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INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

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SEPTEMBER 1954

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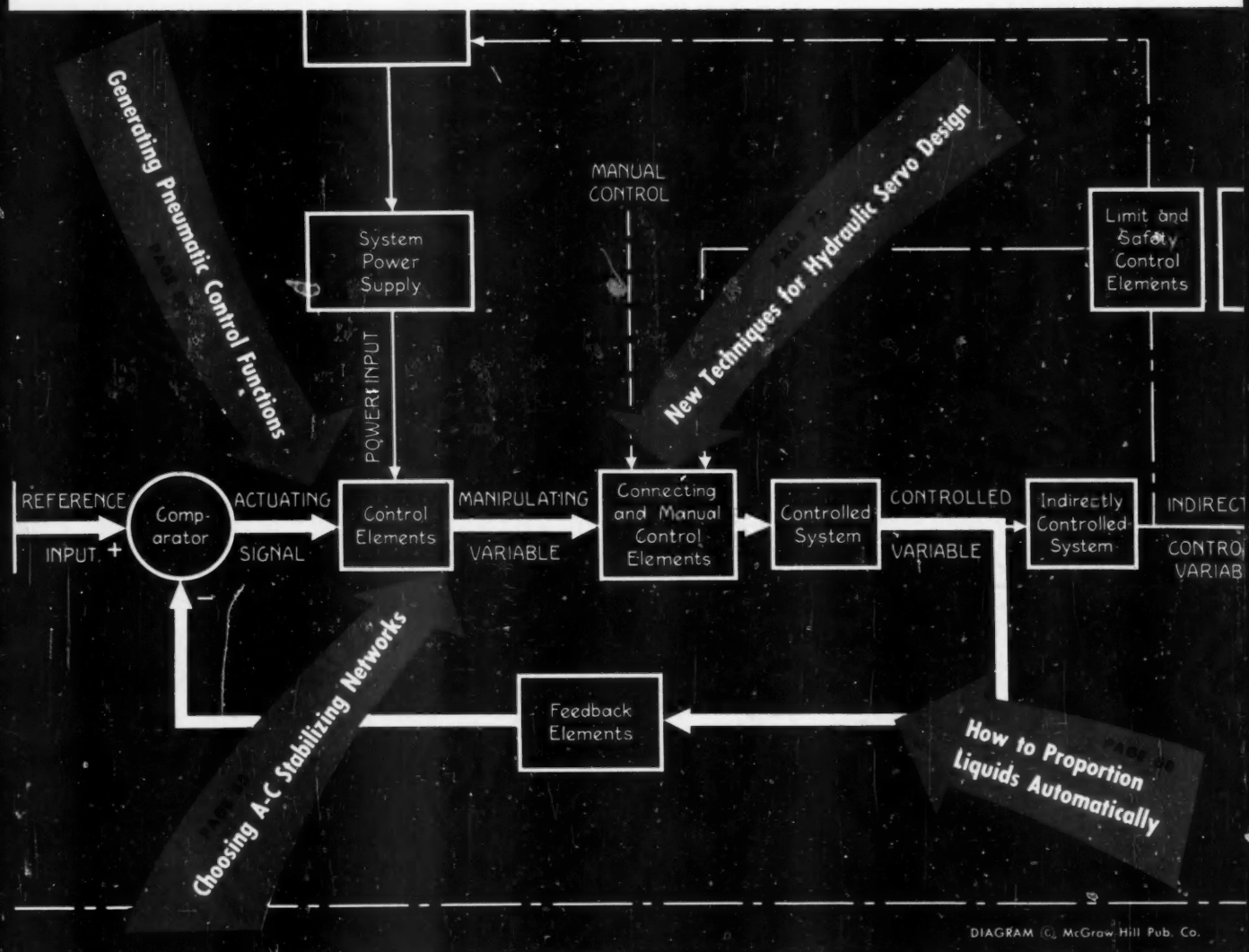

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When Management Buys Control Engineering . . . SEE PAGE 44

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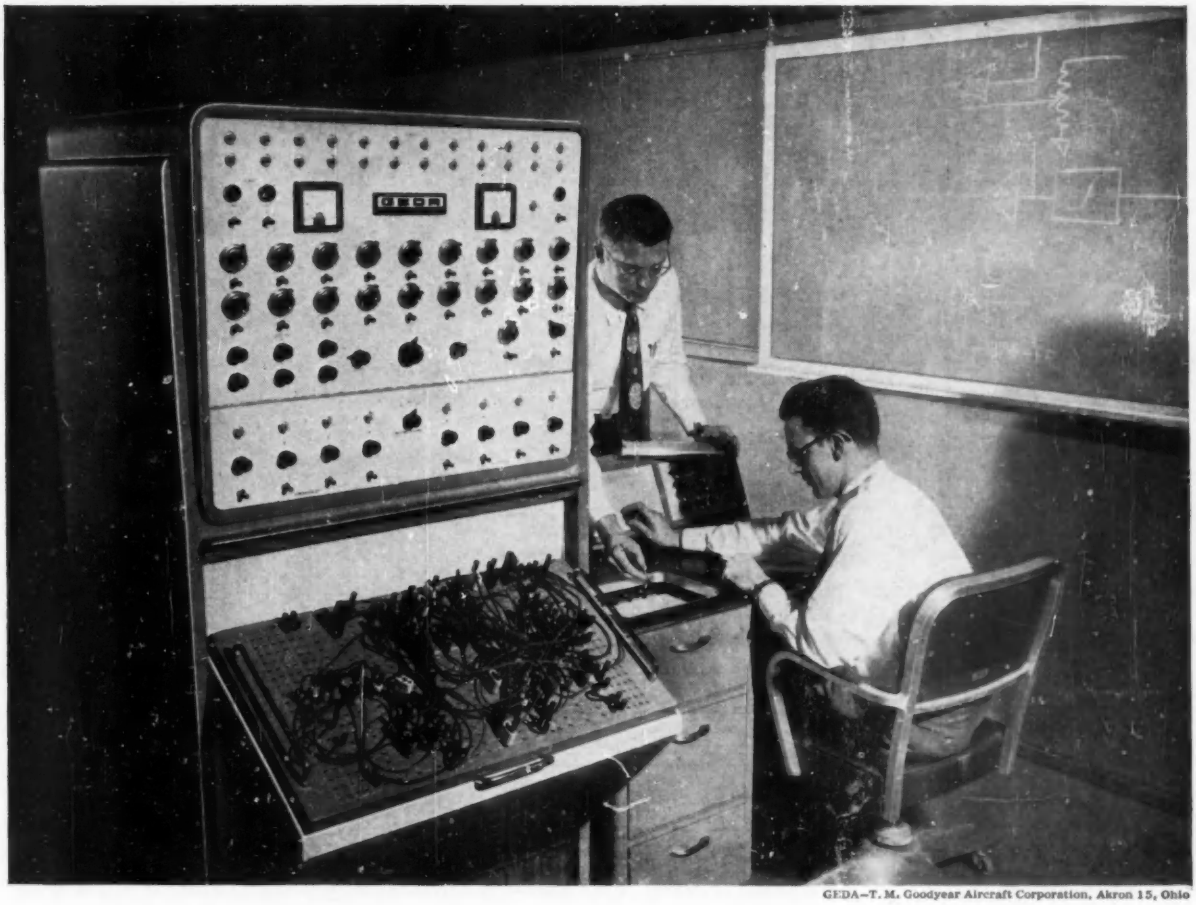

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Control ENGINEERING

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SHOPTALK **Editor to Reader:**

We confess parental pride in the diagram on the front cover. It was conceived a couple of months ago while the editors were grabbing a hurried lunch in the McGraw-Hill dining room. Someone broached a philosophic question: "How would you represent the field of control engineering?" That afternoon we sat down and started to list the main and subsidiary parts of a control loop.

The diagram we evolved—rather, the central portion of it—is the cover for this, our first issue. But it has seen service before. When we started showing it around, several companies were so enthusiastic that they borrowed it. They have been using it to illustrate the scope of control to their customers and their own personnel.

Something else about the diagram. Take a close look at the labels on the various parts. They represent the genesis of a new tongue: control engineering's own universal language. That's another story—one that we plan to cover in installments for years to come. As a starter, we've given it an editorial survey treatment in the Industry's Pulse section, page 35.

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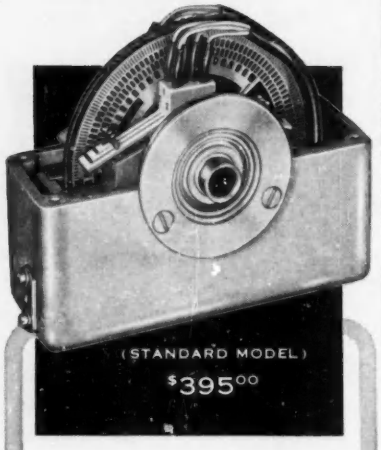

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F E E D B A C K

Reader to Editor:

Almost 2,000 leaders in the field of instrumentation and automatic control read the pilot issue of CONTROL ENGINEERING, *published in January 1954. Here are a few of the letters they wrote in response.*

Filling A Gap

TO THE EDITOR—

Allow me to compliment you on having done an excellent job on producing a magazine that I feel fills a very definite need. We, here in the General Engineering Laboratory of the General Electric Co., do a great deal of control development work, and my specific interests are in the development of computing systems, and I think CONTROL ENGINEERING more nearly satisfies our need than any single magazine we have seen to date.

In the past we have had to review approximately ten magazines to gather the information we needed for our work . . . This control field has now grown so large that it certainly can justify a magazine devoted solely to it. I think you have been wise in foreseeing this need.

K. R. Geiser
Eng. Sup., Computer Unit
General Electric Co.

TO THE EDITOR—

We want to compliment you on the excellent editorial concept presented in this issue. We are keenly aware of the benefits in efficient operation which are made possible by instrumentation and automatic control systems. We want to be aware of progress and possibilities in this field.

Robert H. Bungay
Mgr. of Eng. and Constr.
Union Oil Co. of Calif.

TO THE EDITOR—

I have read this issue with interest and am happy to see a publication devoted to this rapidly growing field . . .

I believe the scope of the subject matter typified by this issue will be well received by industry in general and helpful to prospective customers in particular, as it will accelerate the exchange of information by virtue of attracting more and more papers currently scattered in numerous other publications.

J. H. Dyer
Chief Engineer
Land-Air, Inc.

TO THE EDITOR—

I have shared the sample issue with many of my colleagues, and they too agree this venture is capable of filling a gap in scientific literature.

Control engineering is a broad field and the problems of preparing a journal with a wide-band appeal, and yet with high gain in each region, must be severe. I hope you will never sacrifice rigor for popular appeal.

The complexity of engineering today frequently necessitates a "development engineering team" to attack a problem. One member of this team—frequently a physicist—studies the problem from a theoretical viewpoint. Another, perhaps, from a view of the electronics phase. Another, from the mechanical view. And so on. Each of us then has a separate interest in a problem.

If CONTROL ENGINEERING, however,

PROBLEM EXCHANGE

This magazine's mission is to exchange information among control engineers. In future issues, this FEEDBACK section will publish control problems submitted by readers. Each problem will be reprinted a couple of issues later and accompanied by solutions sent in by other readers. Authors of the best problems and answers will win modest cash rewards.

If you want to become a component in the feedback loop, we suggest you follow this procedure. State your problem briefly. Describe technical details with concise sketches and block diagrams. Explain any economic factors involved.

September 1954 **Control Engineering** Vol. 1, No. 1

Published monthly by the McGraw-Hill Publishing Co., Inc. **Publication office, 99-129 North Broadway, Albany 1, N. Y.** Entry as second class matter at the post office at Albany, N. Y., is pending.
Executive, Editorial, and Advertising Offices: McGraw-Hill Building, 330 West 42nd Street, New York 36, N. Y. Donald C. McGraw, president; Willard Chevalier, executive vice-president; Joseph A. Gerardi, vice-president and treasurer; John J. Cooke, secretary; Paul Montgomery, senior vice-president. Publications Division: Ralph B. Smith, vice-president and editorial director; Nelson Bond, vice-president and advertising director; J. E. Blackburn, Jr., vice-president and circulation director.
For subscriptions, write to: Control Engineering—Subscription Service, 330 West 42nd Street, New York 36, N. Y. Orders must indicate company and position. Allow one month for change of address. Single copies 50¢. United States and possessions: $3 for one year, $4 for two years, $5 for three years. Canada: $4 for one year, $6 for two years, $8 for three years. Latin America: $10 for one year, $16 for two years, $20 for three years. Other countries: $15 for one year, $25 for two years, $30 for three years.
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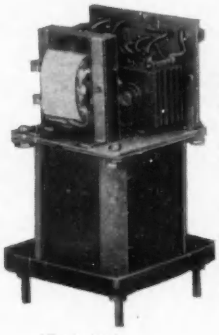

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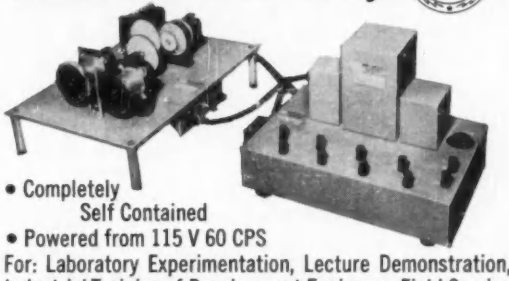

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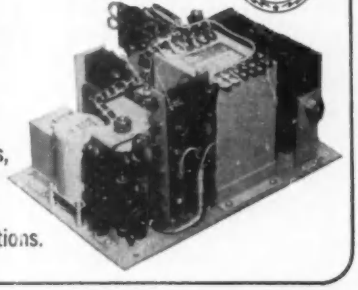

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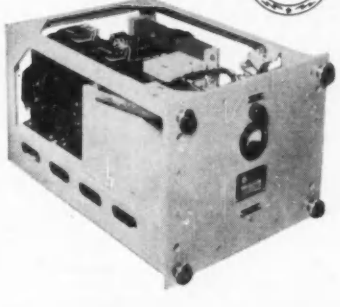

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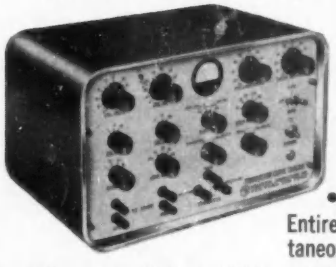

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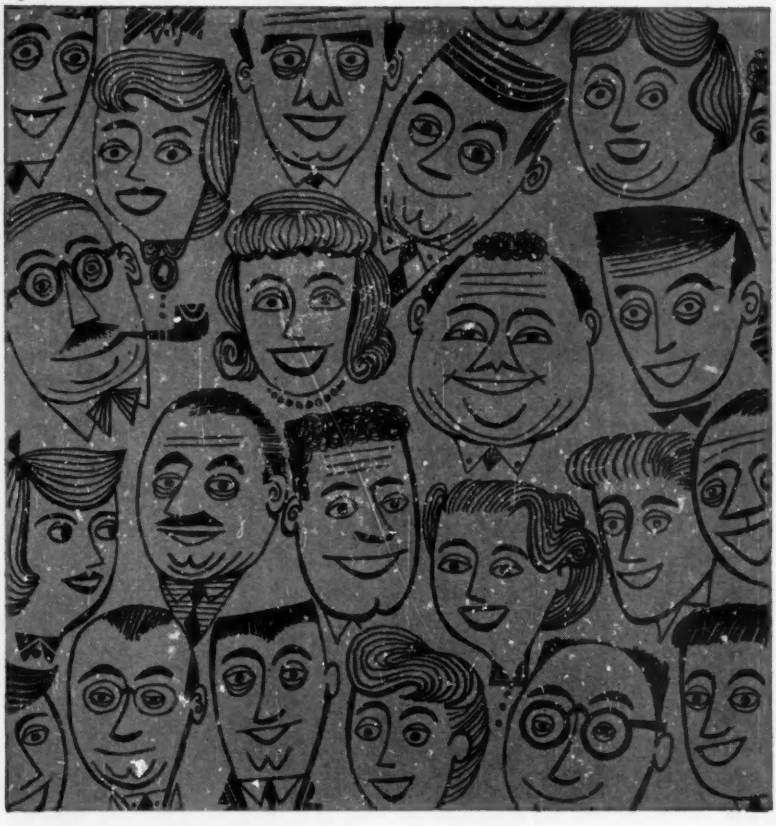

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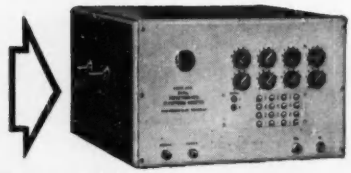

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can be edited to interest each of us in our specialty and still broaden our views in neighboring specialties, the magazine will be of vital service to engineering and science.

Donald J. Lovell
Consulting Physicist
Pasadena, Maryland

Just what we intend to do, Mr. Lovell. —Ed.

Handier Layout?

To the Editor—

The wide variety of articles were interesting and enjoyable.

I must take exception only to the layout . . . Surely with the variety of short articles, book reviews, advertisements, meetings, abstracts, etc. that make up a magazine such as yours, the main technical articles could be so arranged that they start on the right hand page and end on the left . . . Correcting this situation would make your magazine near perfect.

John F. Flanagan
Instrument Engineer
United States Rubber Co.

Unquestionably, Mr. Flanagan's idea would make CONTROL ENGINEERING handier for clipping and filing. In fact, the Ideas at Work section in this issue embodies his suggestion. But ought a magazine force each major article into an even number of pages—a literary Procrustean bed? Or do readers want advertisements used to fill out main features that occupy odd number of pages? For the present, our practice is to exclude advertising from the main feature section and to give each article as much room as we feel it deserves. But we aren't mulish. We should like to sound out other readers on this matter of arranging articles for easier filing.—Ed.

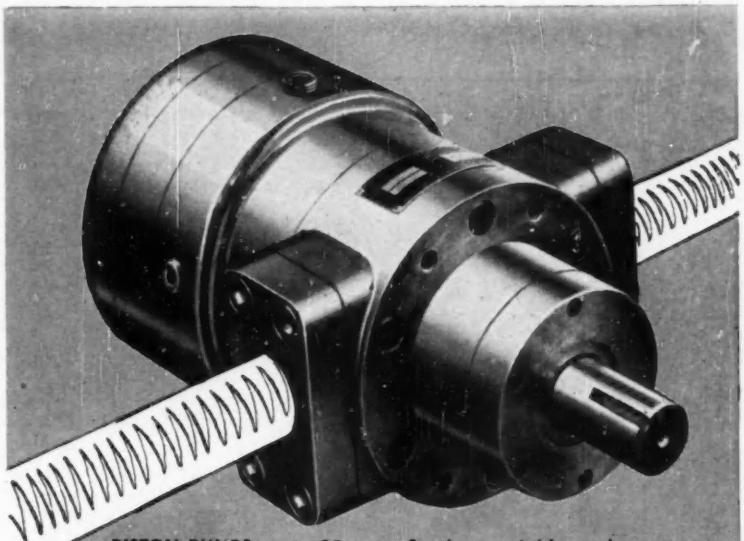
Specific Requests

To the Editor—

I was particularly interested in the articles on analog computers and hydraulic servos . . . My particular interest in a publication such as Control Engineering would be in summary-technical articles such as these and in servo-control system and circuit design details and performance details of servo components such as actuators, gyros, accelerometers, and fluid flow transducers, etc.

R. D. Hill, Jr.
Chief Electronic Engineer
Missile Engineering Div.
McDonnell Aircraft Corp.

This issue contains two summary-technical articles that ought to be right up Mr. Hill's alley: designing hydraulic servos, and choosing ac stabilizing networks. As for those specific requests, give us time and we'll get around to all of them.—Ed.



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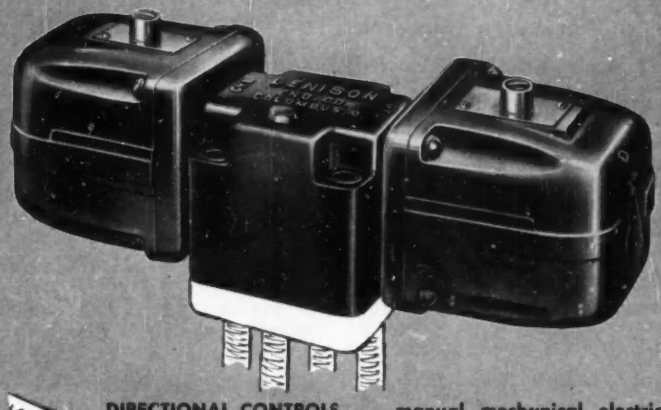

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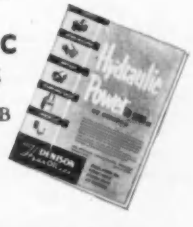

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What's New . . .

Housed in baronial elegance of Princeton showplace, this $300,000 computer welcomed all comers—at a price

Computers Catch the Public Eye

Electronic Associates Puts One to Work in a Princeton Mansion, While Burroughs Builds Another Under Scrutiny of Sidewalk Superintendents

From beauty parlor to fieldstone mansion—this sums up the nine-year history of Electronics Associates Inc.

The beauty parlor in Long Branch, N. J., was good for a start. It was vacant. It was big enough for the original nine associates to begin computer development. And the wiring was adequate. The mansion, insulated by 35 rolling acres near Princeton, befits the company's latest and most ambitious move.

In this impressive building (see cut), EA has installed $300,000 worth of its own brand of computing equipment. Here, for the first time, any man or company can hire a large and precise analog computer to solve problems, without lining up behind government-contract priorities.

Charge is $90 per hour of computer time. From its own ranks or from among its consultants, EA can call on technical and scientific specialists to help formulate problems and feed them into the computer. Their services cost extra.

The Princeton mansion is both elegant and functional. At one end are five roomy and quiet offices where human experts can reduce problems to computable forms. The computer itself stands in a beautifully paneled 40-by-60-ft. room under a lofty gabled roof. Its dual console enables it to work on two problems simultaneously. For more complex tasks, it can concentrate its full powers.

The parts inventory includes 96 operational amplifiers—40 of which can serve as summer-integrators—fifteen servo multipliers, four servo resolvers, five servo function generators, a two-channel X-Y recorder, and a six-channel curvilinear recorder. Accuracy is unsurpassed for analog computers: 0.1 per cent of linear problems.

At the opening of the center, EA president Lloyd F. Christianson explained why it was set up: "One of the purposes . . . is to educate business and industry on the capability of analog computers to solve economically many of their problems with an enormous saving of time. The computation center offers a much broader service than just providing analog computer equipment. . . . It is also interested in management operations control, dynamic systems analysis, and applications engineering."

In short, EA intends to spur demand for its analog computers. And it is set to handle all the business it can get. Starting in 1945 with a handful of youngsters, $7,800, and a Navy

Computer Kibitzers: **The first big computer ever built in public bewilders Philadelphia window shoppers. Completed last month in the display window fronting the Burroughs Corp.'s Vine Street headquarters, the computer has been named the UDEC II. It will provide the only major computer rental service in the area.**

contract, it has now reached a position of leadership in the analog field. Today its eleven-building plant in Long Branch keeps 320 people busy. Gross sales for 1954 will be in the $4-million bracket, with profits after taxes around $400,000.

Controls at The Helm In Atomic Energy Strike

Controls were the heroes during the recent atomic energy strike at Paducah and Oak Ridge. When operating and maintenance workers walked out for three days, a handful of supervisory workers kept up full-scale production of fissionable uranium-235.

Atomic Energy Commission officials in Washington testified that only because of centralized and remote controls were these few men able to run the multi-million-dollar uranium enrichment plants.

A presidential board of inquiry reported that union leadership and Carbide and Carbon Chemicals Corp., which operates the two plants, agreed that U-235 production had not lagged during the strike. If the strike had been prolonged, however, lack of maintenance would have reduced output.

Around The Business Loop

▶ Expansion of Robertshaw-Fulton Controls Co. has now stretched into Canada. In a modern 30,000-sq-ft one-story Toronto building, a new subsidiary, Robertshaw-Fulton Controls (Canada), Ltd., will manufacture and assemble thermostatic controls. The output is destined for Canadian customers in the kitchen range, water heater, and space heater fields.

In the U. S., production has started in the company's new Indiana, Pa., plant. A $500,000 addition to the Anaheim, Calif., plant is nearly finished. And a new $2.5 million factory at Long Beach, Calif., is under construction.

▶ Electronic Engineering Co. of California has begun work on a new $1.5 million Air Force contract. The company will set up a centralized data processing system for the Flight Test Center at Edwards Air Force Base. The aim is to save time and money in evaluating the results of test flights.

▶ Automatic Control Co. of St. Paul, Minn., recently installed a pressure operated system to control automatically the Huntington Beach, Calif., sewage disposal plant. Asked about the sensitivity of the new installation, one of the company's engineers replied: "If a man spits into one of the basins, it's enough of a change for the system relays to sense and send control signals to the pumping equipment."

Lucre and Love At Illinois Tech

After riding an up elevator for more than ten years, starting salaries for engineering graduates may be leveling off.

One indication comes from the Illinois Institute of Technology. Placement director Earl C. Kubicek reports that the average Illinois Tech graduate, class of June 1954, was hired for $363 per month. This was just $1 more than the average 1953 Tech graduate got.

Looking back over his records, Kubicek recalls that ten years ago starting pay averaged only $193. Five years ago it was $282.

Still in the surveying mood, Kubicek finds that his alumni are astoundingly lucky in love. He sent questionnaires to 2,980 members of fifth-year classes, and more than half have replied. Analysis shows that 90 per cent of the classes of 1939, 1944, and 1949 are married. Not one is divorced.

"This is significant," Kubicek points out, "in view of the fact that one of every four marriages in the United States ends in divorce."

Why do Illinois Tech graduates, 90 per cent of them engineers, marry so successfully? Kubicek harks back to his first theme: "Engineering salaries have been increasing steadily for more than fifteen years. Because they are better off financially, there may be less friction in their marriages over

You have in your hands the first issue of a new magazine—CONTROL ENGINEERING. The idea for this kind of magazine first originated in our organization as long ago as 1944. The need for a specialized publication of this character did not seem clear at the time but we never forgot it. From time to time we reexamined both the idea and the technical developments which created an increasing need for a magazine devoted specifically to the design and application of instrumentation and control systems.

Last year, feeling that the time was close at hand when we could launch a magazine in this field with reasonable expectation of success, we intensified our studies of the kind and quantity of subject matter which would be available and of the needs of the potential audience which could put it to good use. We published a pilot issue and checked our ideas and our techniques of presentation with prospective readers. This issue of CONTROL ENGINEERING is, therefore, the result of mature thought, careful research and long-term planning.

I want to assure the 15,000 men in industry who have given evidence of their faith in McGraw-Hill by subscribing—sight unseen—to this new magazine that we are backing CONTROL ENGINEERING with the manpower and the resources which will assure them of outstanding value for their subscription dollars. I believe you will find each issue more interesting and more helpful than the last.

Donald C McGraw

KARL T. COMPTON

While putting together this first issue of CONTROL ENGINEERING, we were shocked and saddened to learn of the death of one of the "team," Dr. Carl T. Compton.

As a director of McGraw-Hill, Dr. Compton enthusiastically supported our CONTROL ENGINEERING project. In his intelligent, constructive way he made invaluable suggestions—always in the form of a quiet question or friendly hint.

He saw immediately ahead the great benefits to be derived from the broader use of the control engineering art, developed in war time. His vision and his calm confidence will be missed. But the memory of the man will enforce a high standard for all of us on CONTROL ENGINEERING.

PROGRESS REPORT...

SINCE OUR ANNOUNCEMENT IN FEBRUARY 1953 OF THE FIRST SUCCESSFUL **TRANSISTOR-MAGNETIC SERVO AMPLIFIER,** WE HAVE DEVELOPED A LINE OF STANDARD, AND MINIATURIZED CONTROLLERS. **These . . .**

Servo Magnetics

are ready now as standard components for your servo loops.

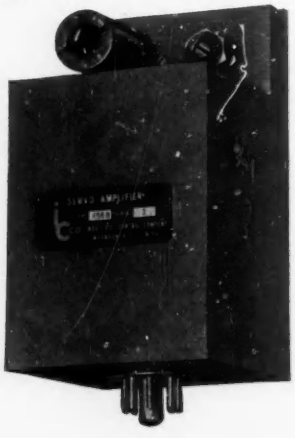
MODEL 420-B
Transistor-magnetic circuitry driving the MK 14 Mod O motor. Small size, light weight, and simple to use. Designed initially for reliable operation in a miniaturized airborne computing loop.

Their versatility and reliability is such that they can be used as standard components, like a servo motor or autosyn. No damping tachometers or power supplies are required. There are only six connections: 2 for input, two for output, 2 for 117 V. 400 cps. Precise regulation of line voltage and frequency is not necessary. Often the nameplate carries full applications data, and system connections.

THESE AMPLIFIERS HAVE RADICALLY NEW CHARACTERISTICS . . .

- **ZERO STABLE WITH LINE VOLTAGE, TEMPERATURE AND FREQUENCY.**
- **POWER SUPPLY—400 CPS LINE ONLY.**
- **BUILT IN SERVO LOOP STABILIZATION.**
- **HERMETICALLY SEALED AND POTTED.**
- **MINIATURIZED AND LIGHT WEIGHT.**

MODEL 456-B
One premium tube, conservatively used, approaches in reliability the mag output stage. Power gain, $6X10^6$. Zero stable to 71° C! Developed for potentiometer follow-up, but works equally well with synchro data. For MK7 Mod O motor.

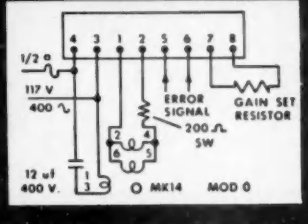


Bypass costly development time and delivery delay in your systems work with these time-tested amplifiers. Whether standard or special, meticulous production techniques insure complete reliability. Delivery on special prototypes is prompt, because of our backlog of engineering designs. These amplifiers are backed by a continuing research and development program.

MODEL 465-B
All mag circuit for MK7 Mod O motor. Full output with 1 ampere turn of control. Supplied with control windings for any current sensitivity. Quick disconnect fasteners and sealed octal header.

May we put our engineering staff and production group to work with you on your automatic control problems?

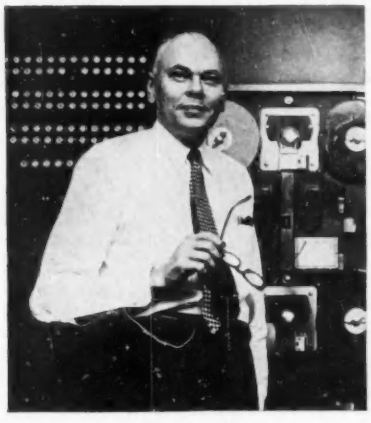
SERVO AMPLIFIER
TYPE 420B SER. [ ]
LINE VOLTAGE 117 V 400 ∿
OPERATING AMBIENT 55° C MAX.
STORAGE AMBIENT 75° C MAX.
FOR BUORD MK14 MOD O MOTOR



ICCO INDUSTRIAL CONTROL COMPANY
WYANDANCH L.I.N.Y.

money problems, one of the major factors in divorce."

Few engineers may roam the multicarat circles, but as long as they are in the chips, the girls remember what are whose best friend.



Aiken: The field is unfolding

Harvard to Award First Data Processing Degree

A year from now a handful of Harvard graduates will be roaming the business world freshly and specially trained in data processing.

The University has just announced that this fall it will enroll candidates for a degree never before awarded: Master of Science in Data Processing. Each candidate must take eight half-year courses—normally a full academic year's work. He will be under the joint jurisdiction of the Division of Applied Science and the Economics Department, who are collaborating with the Graduate School of Business Administration.

Harvard expects the men who complete this course will become leaders in automatic offices, automatic customer billing, automatic inventories, and automatic control of factory operations. Says Prof. Howard H. Aiken, computation laboratory director: "The data processing field is only now unfolding. Great progress can be expected in the next five years."

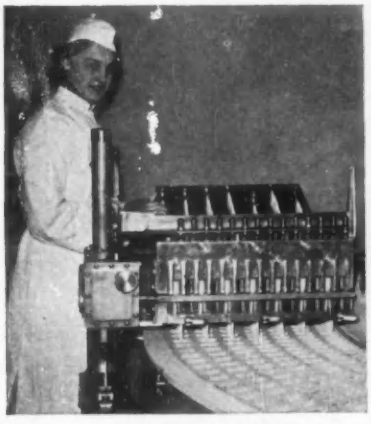
Control Overseas:

Italy

On Sept. 24 and 25 at Stresa, the International Mechanical Engineering Congress will hold a conference on automatically controlled measuring during machining. The meeting follow ten-day Fourth European Machine Tool Exhibition. More than 750 exhibitors from at least a dozen nations will display products in Milan.

At Vojens, Gram Bros., Ltd., has a new automatic machine that makes chocolate-coated ice cream pops at a rate of 14,000 per hour.

Operators feed the machine ice cream, sticks, chocolate, and wrappers. All the rest is automatic. The revolving freezing table has 160 radial rows, each containing seven molds. Hydraulic pressure rotates the table 1/160th of a circle at a step. Feed tank pistons plop a predetermined dollop of ice cream into each mold as it comes along. After moving 35 steps around, the now partially frozen ice cream get a stick handle. Further freezing hardens the cream so that a remover arm can grasp the stick, pull the pop from the mold, and dip it into a pot of liquid chocolate. At the final step, the arms slip the finished pops into wrapper bags, which are held open by an air blower.



Ice cream pops get their sticks

Earlier models have been used in the U.S.A. by the Borden Milk Co.

Russia

"Izvestia" reports that a recently opened automatic line at the J. V. Stalin Combine Plant can make 180 meters per hour of link chain from steel strips. The official government newspaper is shy on details. But the

MASTER HANDLES . . . electrically connected to . . . SLAVE HANDS

and used in conjunction with a three-dimensional television system enable scientists to perform complex manipulations at separation distances up to several hundred feet. Previous mechanically linked units were limited to about twelve feet. Developed by the Argonne National Laboratory, this new manipulator will reproduce the seven basic motions that are used in grasping, lifting, moving, and turning objects. It features specially designed servomechanisms that reflect the work loads and resistances back to the operator. Present load capacity is four pounds. But, Argonne engineers expect that future designs will handle several hundred pounds with a maximum operator force of twenty pounds.

automatic features are said to have freed for other work 100 workers, 1,500 square meters of production space, and "dozens of machines."

The USSR Ministry of Machine Building plans to set up twelve other automatic lines in various farm machinery plants this year. Among them will be:

- Lines for manufacturing and assembling straw conveyors and the cutting parts of combines and mowers at Rostov.
- A special facility at Osipenko for turning out 1.3 million tractor rake teeth annually.
- Lines for making tractor plowshares and plow moldboards at Altai.

Having covered automatic production of plowshares pretty comprehensively, "Izvestia" remains mum on automatic manufacture of weapons.

Sweden

Svenska Metallverken shipped a $1 million fully automatic wire rolling mill to the Anaconda Wire and Cable Co. in U.S.A. Two other Swedish firms collaborated: Asea supplied all the electrical machinery; and SKF delivered the roller bearings.

The dismantled mill, weighing 275 metric tons, was crated in fifteen wooden boxes and loaded on fifteen railroad cars for the trip from Vaesteras to Stockholm, where it was transferred to a freighter.

Dr. Cronje Baeck, chief of Metallverken's machine shops, is now in America helping to set it up. It should be running by the end of the year.

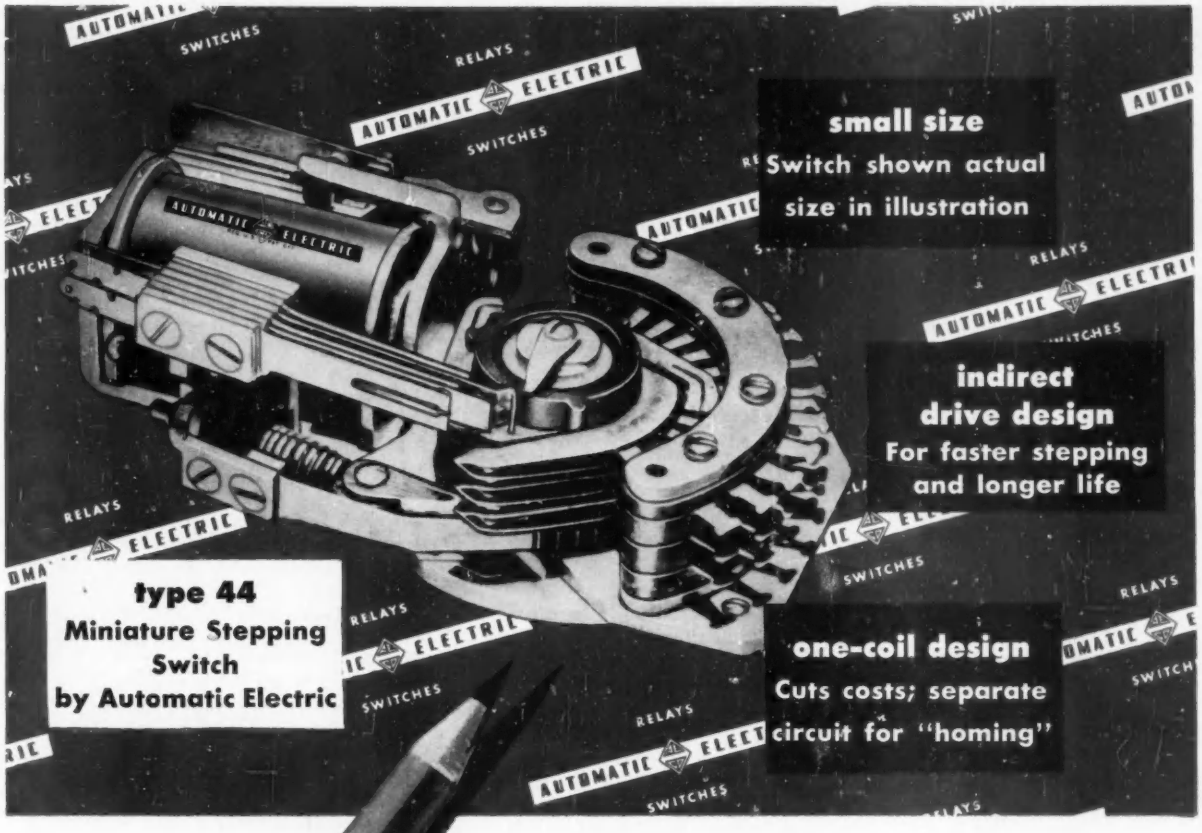
So Round, So Firm, So Automatically Controlled

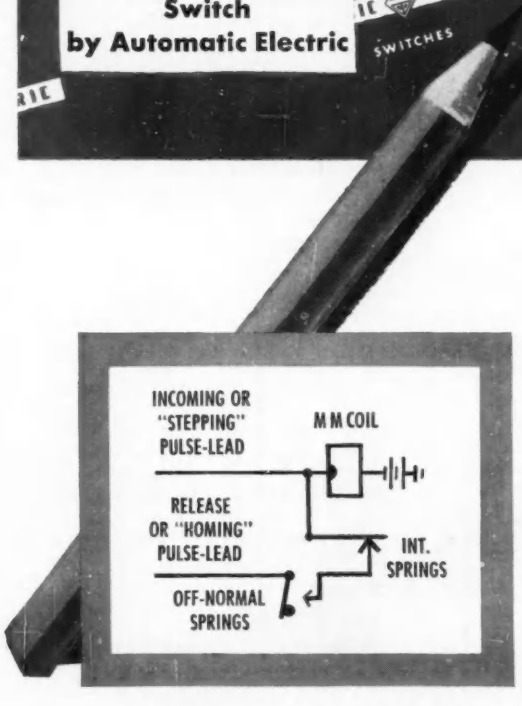
Using a combination of nuclear, electronic, and mechanical principles, the American Machine & Foundry Co. has designed a control system for cigarette manufacturing machinery that will produce perfectly weighted cigarettes. This is something mechanical control alone has never been able to assure. Since this system produces cigarettes of closer weight tolerances, AMF claims that the result of field tests have shown not only improved cigarette quality but also a saving of approximately one and one half tons of shredded tobacco per machine per year.

The Microfeed control system does two things: it measures tobacco density and adjusts the feed to maintain constant density (regulator circuit), and it weighs each cigarette, rejecting those that are over or under an allowable weight band (rejector circuit).

The sensing element for the regulator circuit is a nuclear device activated by twin sources of radioactive material. The beta particles from one source pass through the tobacco rod, while those from the other source pass through a plastic standard absorber. The number of particles that is not absorbed by the rod and the plastic and that reaches the respective ionization chambers is inversely proportional to the density of the tobacco and the standard absorber. The voltages generated in the two ionization chambers are bucked against one another, and the difference is used to adjust a vari-

Nuclear-electronic-magnetic controls insure an even draw every time





How separate "homing" circuit is provided with one-coil operation

Interrupter contact springs open coil circuit near the end of each armature operation—causing switch to step by self-interruption, or by "door buzzer" action.

"Off-normal" contact springs close "homing" circuit on first step of wipers off home position and remain closed until home position is again reached. Thus, after the first step, a "homing" circuit is prepared, and the switch may be "homed" by simply energizing this circuit.

Write for helpful circular CE1678-D

How to make a good product better...without increasing costs

Design engineers everywhere are choosing Automatic Electric's Type 44 Miniature Stepping Switch to insure long service life—often *reducing* costs as they do so! In countless applications, this sturdy switch has operated for more than 200 million operations, with little or no adjustment. The one-coil design eliminates a separate release coil—a saving passed on to the user.

And there are other reasons for such widespread approval: weight and space are saved; indirect drive design give smooth stepping and because there's no wiper "double loading" there's no "galloping"; the unique driving mechanism permits extremely high operating speeds.

Investigate Automatic Electric's Type 44 Switch for your control applications. Here's the first compact, lightweight switch to provide 10-, 20- or 30-point operations. Designed for any dc voltage up to 110, or, with an associated rectifier, for 115 volts 60 cycle ac. The Type 45 Stepping Switch is adaptable to 25-point operation (plus home) using wiper levels singly, or to 50-point operation using wiper levels in "staggered" pairs. For more details on Automatic Electric stepping switches, write for helpful engineering specifications to: Automatic Electric Sales Corporation, 1033 West Van Buren Street, Chicago 7, Illinois. In Canada: Automatic Electric Sales (Canada) Ltd., Toronto. *Offices in principal cities.*

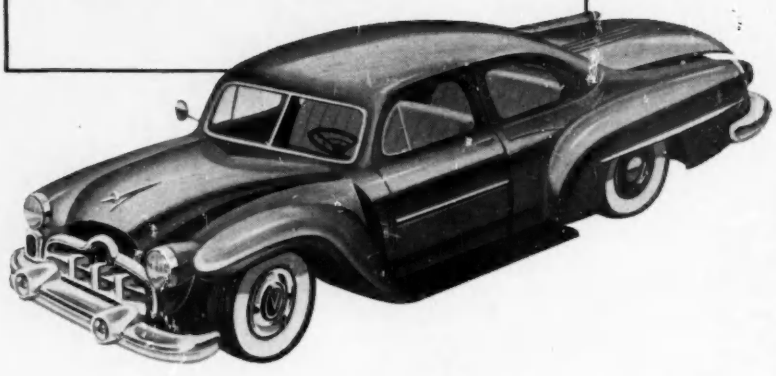
RELAYS SWITCHES

PRODUCTS OF THE INDUSTRIAL DEPARTMENT OF

AUTOMATIC ELECTRIC

CHICAGO

Does your servo system end up like this?



Of course, you've never bought an automobile in pieces, picking up a bumper here, a carburetor there, a clutch somewhere else. Even if you *could* arrive at the appearance and performance of a finished car, chances are it would require countless hours of work and a factory-full of fabricating equipment to integrate the odd sized parts.

Surprising, then, how many companies build servo systems just this way. Buying parts from different manufacturers . . . putting them together and hoping for an ideal system. Either the final result is far below potential efficiency, or the time, labor, machinery, and materials wasted in trying to "fit" the components together boosts the cost astronomically.

Experience proves that complete assemblies of Transicoil components not only assure improved system performance but actually cost less than the total purchase price of the individual components acquired from several sources.

If you are now purchasing servo components from several manufacturers, a serious talk with Transicoil will pay you dividends in lower costs and a better system. But if you require only one component, you can be sure of optimum performance from the Transicoil units you specify.

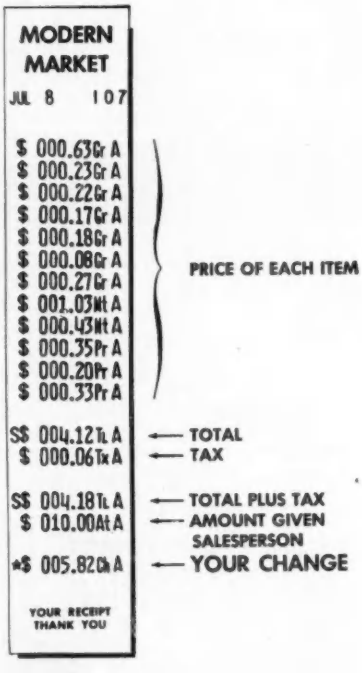
TRANSICOIL

CORPORATION 107 GRAND STREET NEW YORK 13, N.Y.

Miniature Control Motors | Motor and Gear Train Assemblies | Motor, Generator, and Gear Train Combinations | Servo Amplifiers | Plug-In Assemblies

able speed transmission that drives the tobacco feed. The rate of feed is proportionally corrected to the signal. Absorber density can be varied to permit adjustment of the standard for proper tobacco rod density.

The sensing element for the rejector circuit consists of a dielectric bridge with a cigarette-length of rod as one arm. The signal from the bridge is a polarized voltage representing the limits of weight deviation considered acceptable by the manufacturer. If the signal voltage exceeds these limits, the unacceptable cigarette is rejected when it reaches the catcher, about 1½ seconds later. This delay is achieved by an electromechanical memory device that is synchronized to the speed of the cigarette rod.



Supermarket Computer Calculates Correct Change

No longer does the supermarket clerk have to depend on mental or pencil-and-paper arithmetic to determine the amount of change due a customer. This job is done for him now by a new cash register recently introduced by the National Cash Register Co.

This "computer" not only gives the customer a printed record of the individual item cost and total order cost, but also lists the denomination of the check or bill given in payment and the change the customer should get.

CLOSE THE LOOP...

from **MECHANIZATION** to **CONTROL**

PANELLIT has designed and built Automatic Control and Information Systems for the complete control of processes since 1943. Whether you are in a fabricating or a processing industry, Panellit alone offers:

- Basic System Design and Engineering
- *Impartial* selection of instruments and components
- Assembly and Fabrication of *complete* systems
- *Panalarm*—Integrated Alarms for Safety
- *Panascan*—Scanning, Data-Processing and Data-Reduction systems
- Installation, field check-out, inspection

PANELLIT, Inc.

7461 North Hamlin Avenue

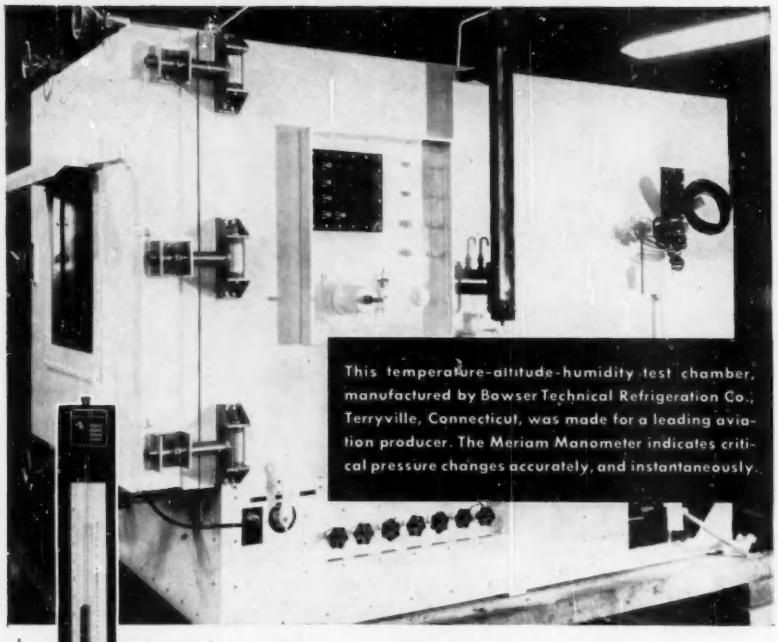
Skokie, Illinois

PANALARM

Alarm and Safety Division

PANASCAN

Scanning and Data-Reduction Division


This temperature-altitude-humidity test chamber, manufactured by Bowser Technical Refrigeration Co., Terryville, Connecticut, was made for a leading aviation producer. The Meriam Manometer indicates critical pressure changes accurately, and instantaneously.

MERIAM

MANOMETER ACCURACY to indicate climb of 10,000′ per minute

Meriam Manometers, Model A-538, illustrated, are used by Bowser Technical Refrigeration of Terryville, Conn. on temperature-altitude-humidity test chambers to give their customers "instrumentation of as high degree of accuracy as possible."

The test chamber illustrated allows testing of products in a range from −100° F. to +200° F., from sea level to 80,000 ft. at a climb rate of 10,000 ft. per minute...and these conditions are contained in a free working space of 3′ wide x 3′ high x 4′ deep.

If your instrumentation problems involve critical indication of pressures which are a function of some desired measurement, call on your MIT* Man to help you solve them. Meriam Instruments are primary standards for indicating pressure or flow of liquids and gases.

*Meriam Instrument Technical Man

THE MERIAM INSTRUMENT CO. • 10934 MADISON AVE. • CLEVELAND 2, OHIO

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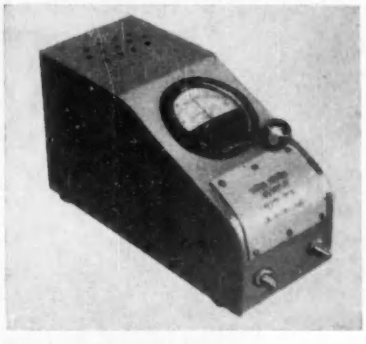
In Canada: Peacock Bros., Ltd., Montreal

MERIAM ★ *Instruments* ★

ESTABLISHED 1911

MANOMETERS, METERS AND GAUGES FOR THE ACCURATE MEASUREMENT OF PRESSURES, VACUUMS AND FLOWS OF LIQUIDS AND GASES

Such items as bottles returned for refund or coupons offered for credit are rung up on the register which automatically lists and subtracts these amounts from the total of the customer's purchase. If the payment offered by the customer is too small, the machine indicates how much money the customer owes instead of the change that is due. For visual checking, all figures are displayed on the register as they are listed. All this machine needs is a sign that pops up and says **Tilt** when somebody tries to pass a counterfeit bill.



What's in the gray box?

Decker Aviation Hints New Measuring Principle

Security classification is scribbling another paragraph in the rumor book. The talk this time is about a brand new principle of measurement developed at the Decker Aviation Corp., Philadelphia.

When incorporated in an analog transducer, a single device of this new breed is supposed to replace an impedance bridge, a phase sensitive rectifier, and a voltage amplifier. It can, it is said, measure any phenomenon reducible to changes of capacitance, resistance, or inductance.

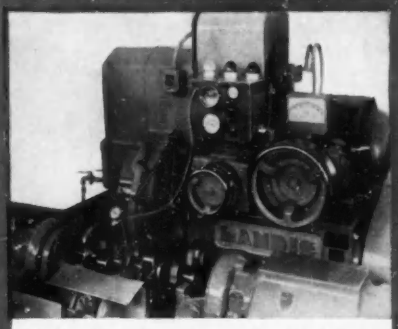
One of the first applications is the differential pressure gage, shown in the picture. Measuring only 4-by-4-by-8 inches, it is so sensitive that a pressure difference of merely one millimeter of water produces a 5-volt signal output.

Declassification is expected to end the mystery some time in September.

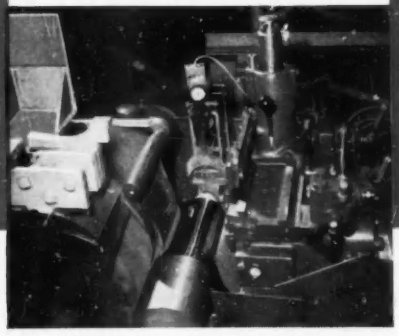
Technical Society Notes:

IRD, ASME

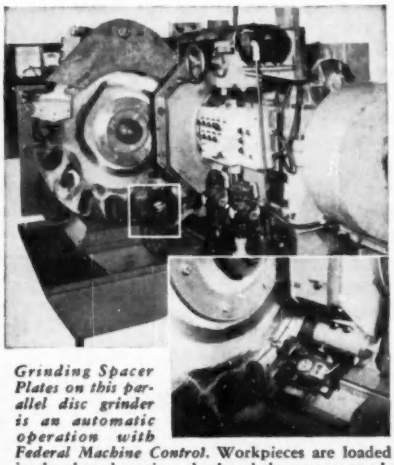
A quickening of activity in the Instruments and Regulators Division of ASME is evident in the inauguration of an "*IRD Newsletter.*" First is-



Grinding Main Journals on a Crankshaft is done quickly and without scrap with this Federal Air-Electric Grinding Gage. The operator loads the machine, snaps the caliper on the work and starts the machine cycle. When the work is down to size, the wheel automatically backs up. The large Air Dial and the three signal lights provide visual checks on the progress of the grinding. With this Machine Control Gage it is impossible to grind undersize scrap because the gage automatically backs the wheel up when work is to size.

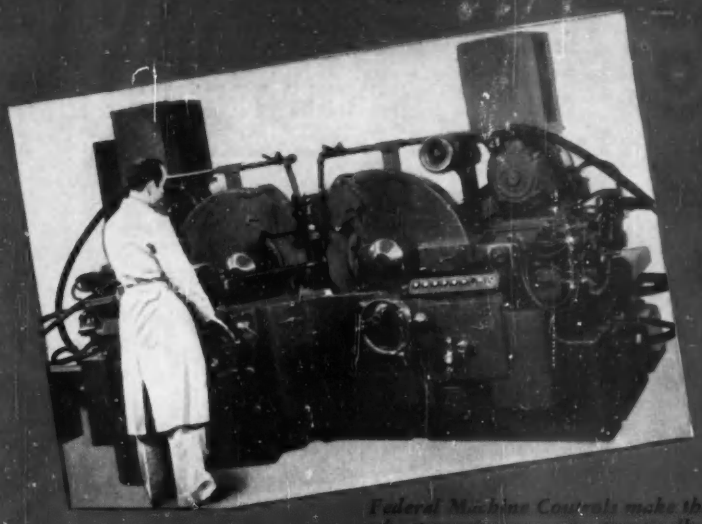


This Federal unit, employing an Arnold continuous caliper type grinding gage, automatically controls the size of the journal surfaces of 1100 lb. freight car axles. The gage, ordinarily retracted to provide loading clearance, automatically springs onto the work and takes control of the grinding process at the start of the grinding cycle. Signal lights tell the operator when work is "over size", "near size", or "to size" and are connected electronically to the machine controls so the grinding cycle is automatically stopped when the required size is obtained. Tolerances are consistently maintained well within the plus 0.0005", minus 0.0000" specified.



Grinding Spacer Plates on this parallel disc grinder is an automatic operation with Federal Machine Control. Workpieces are loaded in the slotted carrier wheel and the gage controls the feed of the wheels to compensate for wheel wear. Corrections are made alternately to each wheel-head to maintain the centering of the carrier wheel. Automatic controls assure continuous production of good pieces, eliminating scrap.

A few of many applications



Federal Machine Controls make the grinding of automotive rear axles practically automatic.

FEDERAL *Automatic* MACHINE CONTROL GAGES

have established their efficiency

AUTOMATION is a new term applied to an idea that general machinery manufacturers have been doing ever since Eli Whitney invented his Cotton Gin. But, controlling Machine Tools automatically so that they produce work to required sizes is comparatively new.

Federal, however, has been designing and building Gages for this purpose for several years. We offer this tried and proven experience to all builders and users of machinery where Automatic Dimensional Control of Machine Tools is desired. We can handle all phases of the work; from work-handling through gaging, machine control and disposal.

Federal is ready to provide standardized package units for air, electrical, electronic or combination controls and **will cooperate with your engineers to adapt these to your machine requirements.** Call —

FEDERAL PRODUCTS CORPORATION
4409 EDDY STREET • PROVIDENCE 1, RHODE ISLAND

SOME OF MANY POSSIBILITIES

Percentage reject control. A simulation of automatic statistical Q.C.

Automatic shut-off when dimension out-of-control.

Automatic tool adjustment or compensation.

Tool Adjustment Signalling.

Automatic classification according to dimension.

Automatic line operation signals, etc., etc.

Ask **FEDERAL**
FOR ANYTHING IN MODERN GAGES...

for Inspecting, Measuring, Sorting or Automatically Controlling Dimensions on Machines

SIMPLIFY CIRCUIT TRIMMING *with*

BOURNS

sub-miniature

TRIMPOTS®

TRADE MARK

- **RESOLUTION: AS LOW AS 0.25%**
- **POWER RATING: 0.25 WATT AT 100° F.**
- **WEIGHT: ONLY 0.1 OZ.**

BOURNS ***TRIMPOT*** is a 25 turn, fully adjustable wire-wound potentiometer, designed and manufactured exclusively by BOURNS LABORATORIES. This rugged, precision instrument, developed expressly for trimming or balancing electrical circuits in miniaturized equipment, is accepted as a standard component by aircraft and missile manufacturers and major industrial organizations.

Accurate electrical adjustments are easily made by turning the exposed slotted shaft with a screw driver. Self-locking feature of the shaft eliminates awkward lock-nuts. Electrical settings are securely maintained during vibration of 20 G's up to 2,000 cps or sustained acceleration of 100 G's. BOURNS ***TRIMPOTS*** may be mounted individually or in stacked assemblies with two standard screws through the body eyelets. Immediate delivery is available in standard resistance values from 10 ohms to 20,000 ohms. BOURNS ***TRIMPOTS*** can also be furnished with various modifications including dual outputs, special resistances and extended shafts.

BOURNS *also manufactures precision potentiometers to measure Linear Motion; Gage, Absolute, and Differential Pressure and Acceleration*

BOURNS LABORATORIES

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Bergman: IRD choice

sue of the biannual newsletter came out in August. E. S. Cobb, associate editor of "Product Engineering" is its editor.

A. S. Iberall, Consultant, Cleveland, Ohio, has energized his IRD Theory Committee to the extent that it is organizing three technical sessions for the annual ASME meeting this December in New York. The sessions will deal primarily with the theory of basic instrument elements.

Members of the IRD executive committee taking office in December are: Dr. J. A. Hrones, W. E. Belcher, R. E. Clarridge, R. Oldenburger, Dr. D. J. Bergman. Dr. Bergman was unanimously chosen as new member by postcard returns from the division membership. He brings to the committee 33 years' experience in the oil refinery business. Dr. Bergman has been active in the development of processes for the production of high-octane aviation and motor fuel. These processes for the production of high-polymerization, dehydrogenation, fluid catalytic cracking, alkylation, and catalytic reforming. He is a member of ASME, ACS, ISA, ASTM, and API.

IRE

IRE plans to form a Professional Group on Automatic Control Technology this fall. Mr. Robert B. Wilcox, Raytheon Manufacturing Corporation, Waltham, Mass., organized the effort which precipitated the plans. Aided by a small group including Mr. John Ward, M.I.T., Cambridge, Mass. and Mr. Cledo Brunetti, General Mills, Mechanical Division, Minneapolis, Minn., Mr. Wilcox circulated petitions which drew 150 signers from the New York-New England area and 50 from the area around Minneapolis.

The group will eventually hold

What the Control Engineer Should Know About SUPERIOR TUBE

ONE SOURCE FOR ALL YOUR NEEDS. Superior makes the widest range of alloys available in tube form—offers you as standard products what many firms would classify "specialty" tubing. You can get round or shaped tubing to standard specifications or to your own design. You can get capillary tubing, pointer tubing, oval and flattened tubing for Bourdon springs, electronic tubing, pressure and superpressure tubing, telescopic sizes and large O.D. light wall tubing. Over 55 analyses are available in carbon, alloy and stainless steels; in nickel and nickel alloys; in beryllium copper, titanium, zirconium. All analyses are available in .010" to 5/8" O.D. and certain analyses in light walls up to 2½" O.D.

SUPERIOR WORKS WITH YOU. Superior is a specialty redraw mill that produces tubing to your specifications. No finished sizes of tubing are carried in mill stock except for sample experimental lots. Every order is produced as it is received. Our engineers are thoroughly familiar with small tubing, its production techniques and end uses, because Superior has always worked closely with users and fabricators of tubing in nearly every industry. It is their aim to supply you with the *right* analysis in the *right* temper with the *right* finish to fit your particular problem or condition.

Superior is more than willing to tackle your smallest developmental order—and more than able to handle your largest production order.

SUPERIOR QUALITY. The quality which users have come to expect from Superior tubing is no overnight accomplishment. Rather, it is the result of years of experience plus a continuing search for improved production and control methods. That is why Superior can offer you close tolerances; bright, clean O.D. and I.D. surfaces ready for fabrication; and a thorough metallurgical control of quality. Superior tubing is a constant; its behavior, in production and end use, is predictable order after order.

SUPERIOR METHODS. To apply precision methods and quality controls to the production of tubing, we have developed many laboratory, production and inspection techniques which are unique with Superior—nondestructive testing for one instance, or either the vacuum or controlled atmosphere annealing of cold-drawn materials for another. Our physical, chemical and metallurgical labs conduct thousands of tests annually as part of the control of tempers, finishes, tolerances, etc. The results of these tests are available to you without charge.

Although Superior carries no mill stock, distributor warehouses the country over stock standard analyses in many sizes and tempers for prompt shipment.

Superior's tube specialists will be glad to work with you in developing, designing and producing the tubing you need. If you have a problem involving tubing, write or wire at once. For further technical information, ask for Bulletin 32. It's free. Just fill in and mail the coupon.

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2055 Germantown Avenue
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Round and shaped tubing available in Carbon, Alloy and Stainless Steels; Nickel and Nickel Alloys; Beryllium Copper; Titanium; Zirconium

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The big name in small tubing

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All analyses .010" to 5/8" O.D.
Certain analyses in light walls up to 2½" O.D.

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- Components procured
- Wiring & Assembly completed
- Internally and externally finished
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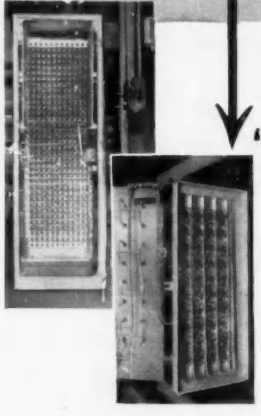
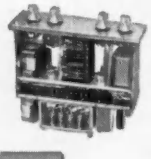
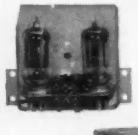
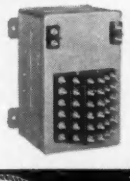


Typical "PACKAGE" Assemblies by Electro-Seal







- Counting chains (fixed or sequential)
- Test and inspection sets
- Remote telemetering controls
- Carrier equipment
- Private telephone switchboards
- Control cabinets
- Electro-mechanical controls
- Special enclosures
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meetings and publish quarterly transactions, as the existing IRE professional groups do.

AIChE

Publication of the "AIChE Journal" begins with its first issue in January, 1955. Dr. R. Harding Bliss, professor of chemical engineering and fellow of Jonathan Edwards College at Yale University, will edit the journal in addition to carrying his teaching program at Yale.

Dr. Bliss authored sections of the "Chemical Engineers' Handbook" by J. H. Perry and "Chemical Engineering Economics" by Chaplin Tyler.

Important Moves By Key People

▶ Kenneth Slawson has been promoted to vice-president of Sperry Corp.'s Ford Instrument Division. Mr. Slawson joined Sperry in 1928. From 1946 he managed the E. G. Staude Mfg. Co. Division, which was sold to Bryant Chucking Grinder Co. last year.

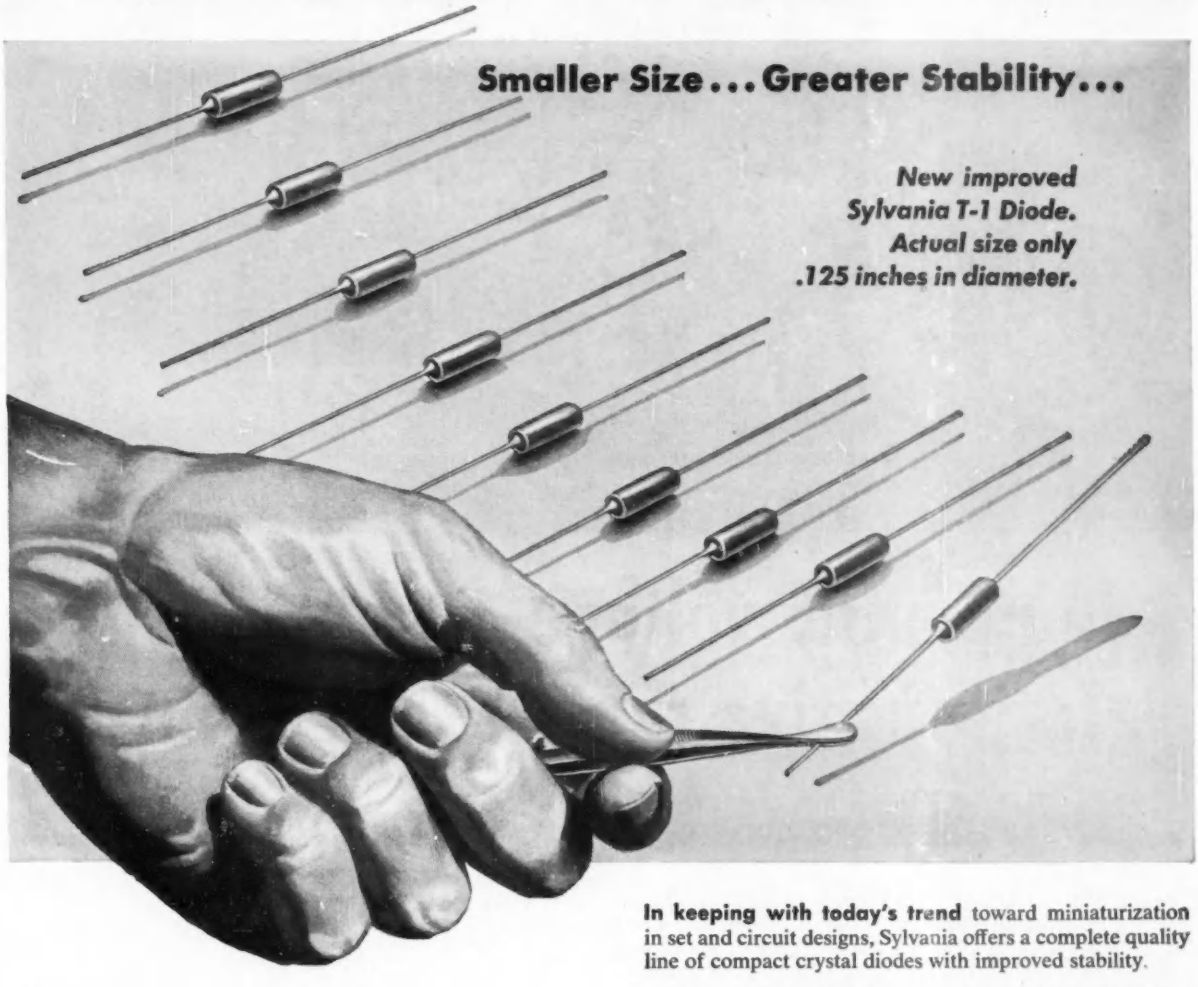
Slawson, new Ford Instrument V-P

▶ Walter P. Hooper is now administrative vice-president of Panellit, Inc. Formerly a public accountant and president of the Wales-Strippit Corp., Mr. Hooper will take on the bulk of Panellit's administrative responsibilities. This will leave president Albert F. Sperry free to concentrate on a new automatic-control research and development program.

▶ William C. Jordan has resigned as executive vice-president of Hughes Aircraft Co. He had taken the post temporarily last October following a mass exodus of technical and executive personnel.

Sylvania Offers You...

A NEW COMPACT DIODE LINE



In keeping with today's trend toward miniaturization in set and circuit designs, Sylvania offers a complete quality line of compact crystal diodes with improved stability.

These new components measure only .125 inches in diameter . . . require only 1/6th the space of former units. At the same time, due to advanced manufacturing techniques and Sylvania's new automatic precision equipment, they provide far higher performance records.

With these tiny diodes, you can be assured of more uniform characteristics and closer tolerance limits . . . even on large quantity orders.

This new T-1 Series also has recently passed MIL-E-1B moisture-resistance tests. Now available in capacities for every need. For full details write to Dept. 4E-5209, Sylvania today!

Another reason why it pays to specify Sylvania!

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Sylvania Electric Products Inc., 1740 Broadway, New York 19, N. Y.

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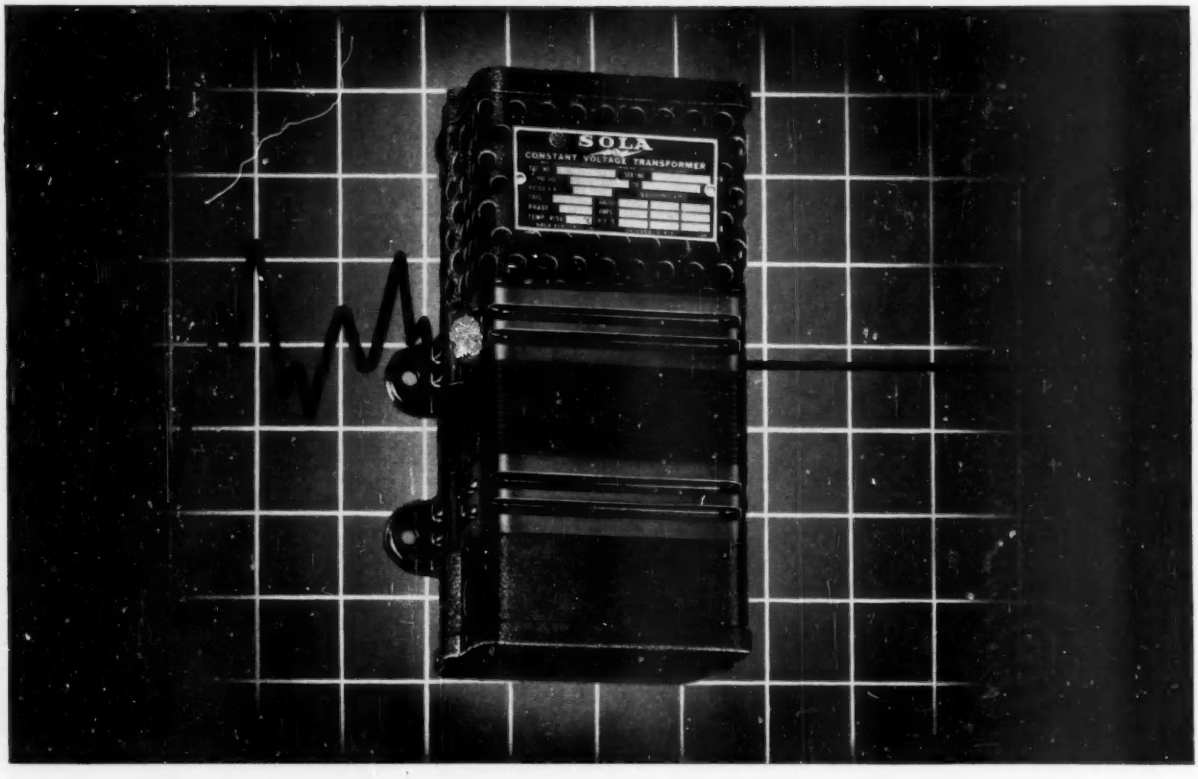

Automatic voltage stabilization for sensitive control components

You can eliminate the variable of erratic line voltage on voltage-sensitive elements of automatic control equipment. Do it simply and economically with the Sola Constant Voltage Transformer.

The Sola stabilizer is a static-magnetic regulator which differs from regulators depending solely upon saturation of core materials; or electronic types employing tubes. Their characteristics, listed below, make them ideal for controlling input voltage to voltage-sensitive electronic and electrical control components.

1. Regulation within ±1%, with primary voltage (transient or continuous) variations as great as 30%.
2. Response time less than 1½ cycles.
3. No moving or wearing mechanical parts, nor vacuum tubes; requires no manual adjustments.
4. Completely automatic, continuous regulation.
5. Self-protecting against short-circuits on output.
6. Current-limiting characteristic protects load equipment.
7. Isolates the input and output circuits.

Forty-three Sola stock units are available in a wide variety of ratings, voltages and types. In addition, custom-designed units can be manufactured (in production quantities) to meet specific requirements.

The experience of the world's largest manufacturer of constant voltage transformers is available to you. We invite you to discuss your voltage stabilizing problems with a Sola Sales Engineer.

SOLA *Constant Voltage* **TRANSFORMERS**

WRITE FOR LITERATURE. Sola Constant Voltage Transformers are completely described in a 24 page manual. Write for a copy of 261-CV-200 on your letterhead, please.

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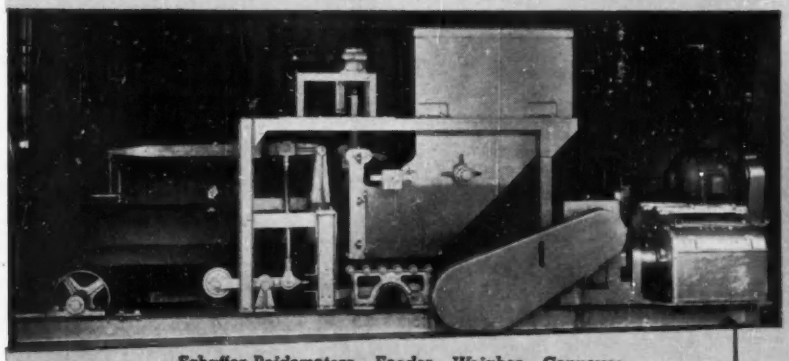
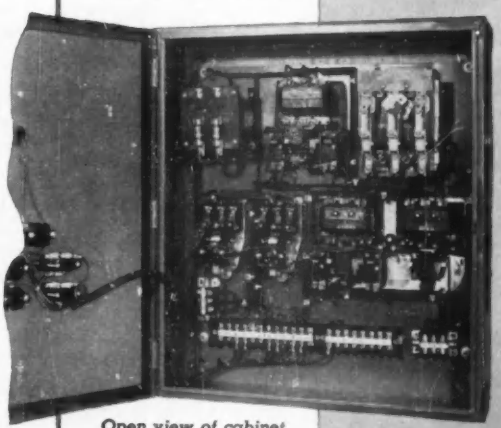
SCHAFFER POIDOMETERS rely on CLARK CONTROL for accurate feeding, weighing and conveying

CLARK Type "CY" Starters *are basic units in Control System*



Schaffer Poidometers—Feeder—Weigher—Conveyor

Closed view of Clark Control Cabinet



Open view of cabinet

Dependable, accurate control is essential on poidometers designed to deliver materials to machines or process operations in exactly correct amounts.

The Schaffer poidometer illustrated is one of four which feed clinker and gypsum in lump state to a ball mill for pulverization. The CLARK control panel incorporates controls for two motors—one operating the conveyor belt at a fixed travel speed, the other operating the hopper gate. A weighing beam actuates limit switches, causing controlled motor to move gates up or down, to keep proper weight of material flowing.

When two or more poidometers are used for proportioning materials, controls are provided so that stoppage of one machine automatically stops the others to prevent improper proportioning.

CLARK Type "CY" AC Motor Starters are ideal for this and other control applications where accuracy and dependability are requisites. The new arc-quenching principle, which forces the arc to move continually from a hot to a cold spot on contact surfaces effectively reduces contact wear—thus providing less down time and longer life.

These and other important exclusive features of CLARK Type "CY" Starters can improve the efficiency of your machines. Let us show you how.

The **CLARK** **CONTROLLER** *Company*

Engineered Electrical Control

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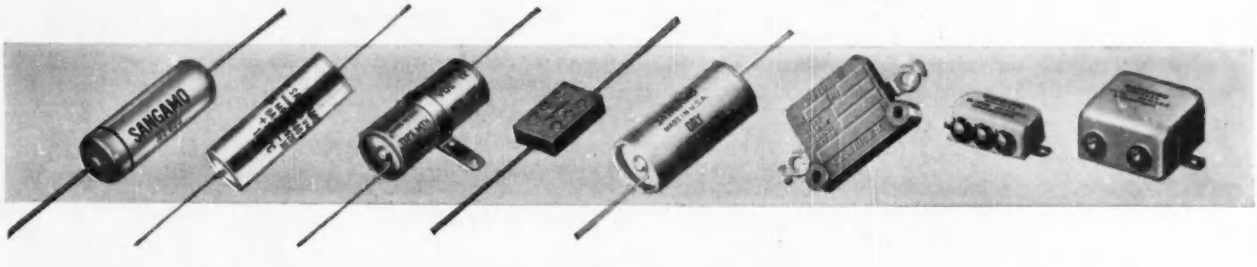
...that's why IBM uses Sangamo

The amazingly complex IBM "702" electronic calculator is hailed as the fastest and most flexible commercial data processing system ever devised. The central Arithmetical and Logical Unit performs calculations and makes decisions at a rate of more than 10,000,000 operations in an hour. Data and instructions for processing are stored in an electrostatic memory bank of cathode ray storage tubes. Output can be in the form of punch cards at the rate of 100 per minute.

A machine like this needs components that assure maximum performance to meet its exacting demands. That's why several different types of Sangamo Capacitors are used in the 702.

If you need capacitors for demanding electronic applications, Sangamo engineers can help you. You can choose from a complete line of paper, mica, electrolytic and button type capacitors for every industrial, electronic, and radio application.



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Stability
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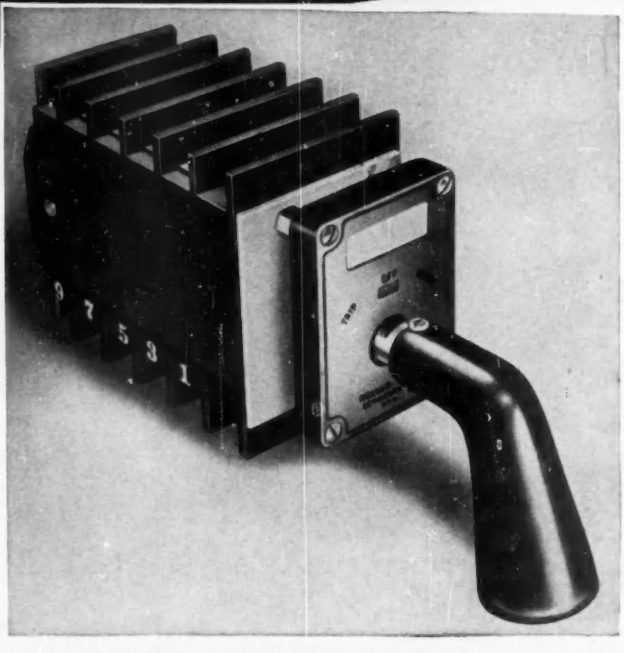
Where Panel Space is at a PREMIUM . . .

use the R-4 Miniature Rotary Switch

Illustrated above is the R-4 Miniature Rotary Switch—available now for those applications where space is at a premium. Featuring unit construction, silver contacts, 600 volt insulation, enclosed mechanism and choice of handles, the R-4 provides the same high interrupting capacity, long life and flexibility found in the standard R-2 Control switch illustrated at right.

Both R-2 and R-4 Rotary switches are available in a wide combination of contact arrangements for Instrument—Control—Transfer—Auxiliary and Special Applications.



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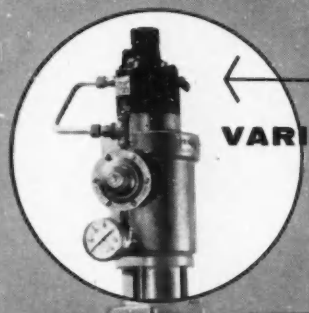

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RECEIVES 3 TO 15 PSI SIGNAL

OUTPUT SHAFT RESPONDS WITH VARIABLE SPEEDS

MOTORS

¼ TO 50 HP

U.S. VARIDRIVE

THE MIRACLE MOTOR

WITH **VARITROL®**

Now any process requiring automatic variable speeds can be driven by U. S. Varidrive with Varitrol control. For more than 20 years the Varidrive has been recognized as the most compact and efficient device for obtaining variable speeds, with ratios up to 10:1 and capacity from ¼-50 HP. Varitrol is a new control device which regulates the speed of a Varidrive in response to a signal. The signal is obtained from a standard type of pneumatic instrument sensitive to such variables as:

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Humidity	Weight
Pressure	Tension
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Many firms are increasing productivity with Varitrol control. Quality of product is improved, human effort is reduced. Lower costs result in better salability of your products.

U. S. Engineers are experienced in variable speed problems, and can help you apply Varidrives to your process.

Request new Bulletin on Varidrives with Varitrol automatic control. Indicate if you would like additional literature on Varidrives.

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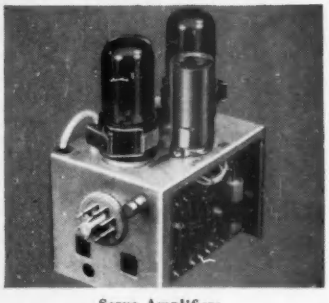
Hi-Precision SERVO COMPONENTS

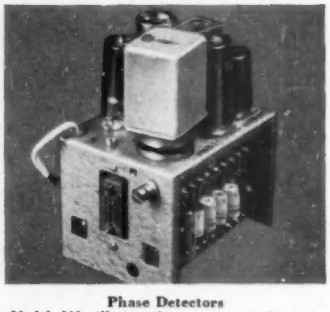
From Link Aviation comes a new kind of flexibility for servo design and manufacture. Tested and proved in production electronic equipment, Link *Hi-Precision* Servo Components can be used interchangeably in laboratory prototypes and actual production models. This new technique assures in-use performance during research — cuts costs in production design — saves time in tooling-up in the fast-changing electronics field.

Linear Phase Detectors
Model 302, illustrated, produces a D.C. voltage at its output proportional in magnitude to an A.C. 60 cycle voltage at the input with polarity proportional to the phase at the input.



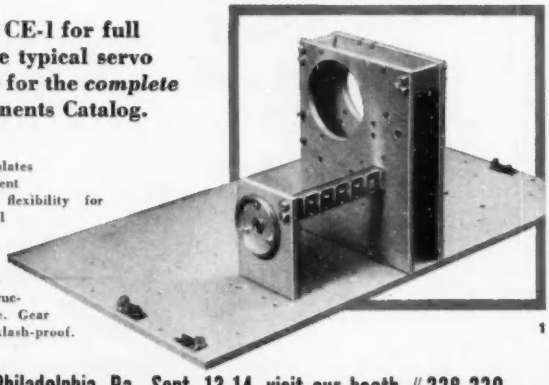
Servo Amplifiers
Model 300, illustrated, provides a versatile high gain, low phase shift for use at 60 and 400 cycles. The amplifier can be coupled directly to plate to plate servo motors or matched to a specific motor.

Summing Amplifiers
Model 301, illustrated, performs the functions of isolation with low output impedance, as a phase inverter — in conjunction with a network in the grid circuit, as a summing amplifier.



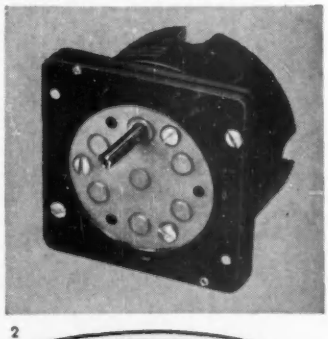
Phase Detectors
Model 303, illustrated, compares a 60 cycle voltage input of reversible phase with a reference voltage of fixed phase. Ultra sensitive, Model 303 requires only a minimum differential to energize or de-energize a relay.

Write Department CE-1 for full specifications on the typical servo parts shown here — or for the *complete* Link Servo Components Catalog.



1 **Hi-precision** base and upright plates are designed to eliminate alignment problems — yet permit full design flexibility for combining electronic and mechanical units in a single compact unit.

2 **Hi-precision** gear boxes range in ratio from 20:1 to 3125:1 — feature virtually friction-free construction — low inertia — and high torque. Gear boxes in all ratios are practically backlash-proof.



1 2

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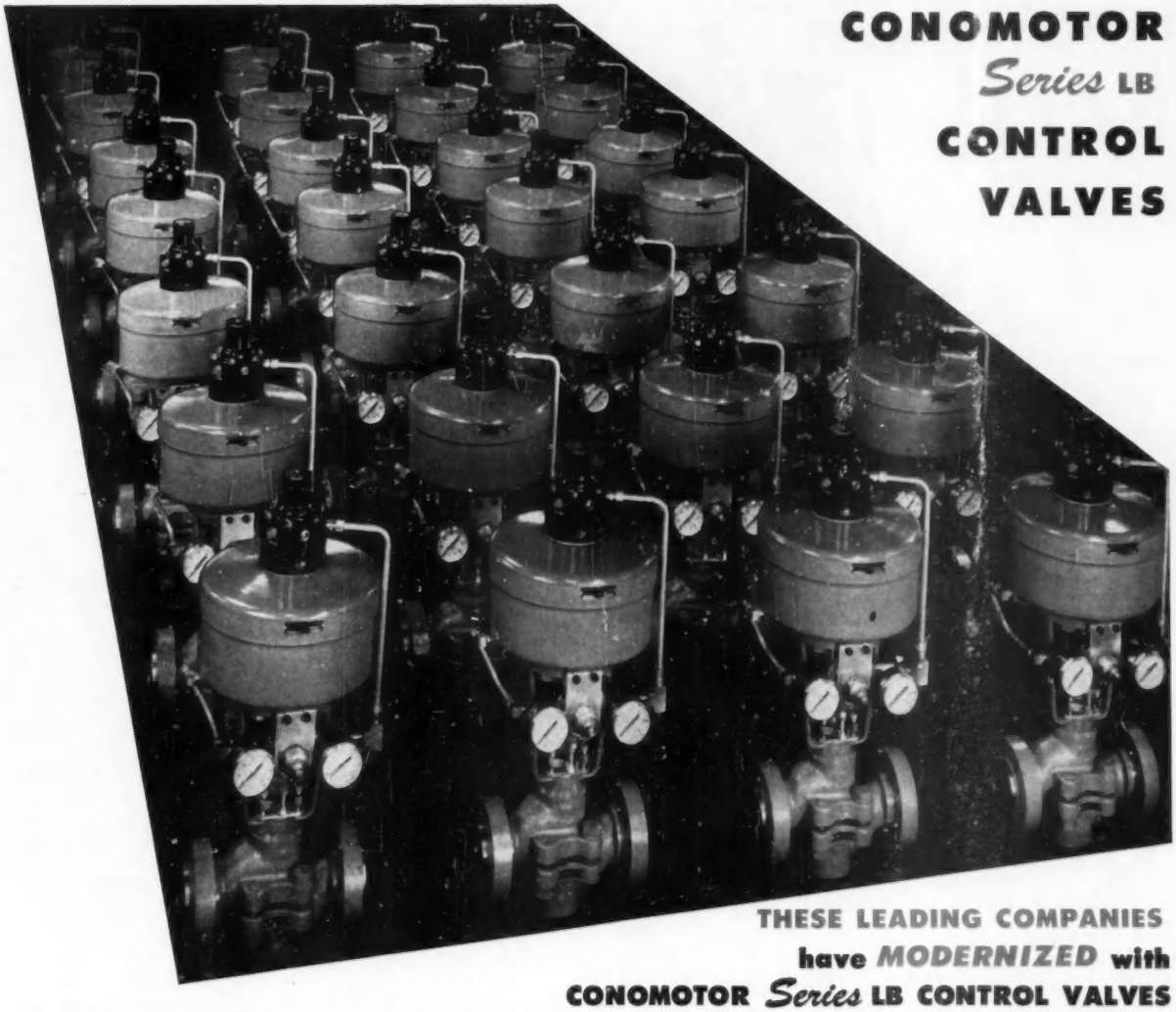

CONOMOTOR *Series* LB CONTROL VALVES

THESE LEADING COMPANIES have *MODERNIZED* with CONOMOTOR *Series* LB CONTROL VALVES

Progress cannot be denied! Naugatuck Chemical Division of U. S. Rubber Company has completely equipped a new plant with Conomotor Series LB Control Valves for temperature control on reactors. U. S. Steel is using a large quantity of these valves for various services in their new coal chemical facilities in the midwest. E. I. du Pont use Conomotor Control Valves for their complete valve equipment in a new pilot plant at their Eastern Regional Laboratories. Armstrong Cork Co. has standardized on Conomotor LB Valves for an extensive modernization program. These important decisions were based on thorough evaluation of design, performance and cost. When companies of this caliber approve and adopt a new advance in process control, you can rely on their judgment. These and other new installations are typical of the important part Conoflow final control elements play in the modern industrial evolution to automatic control. Whether you have a new plant or plan to modernize your old plant it will pay you to talk to Conoflow.

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- Curtiss-Wright Corp.
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OC-400

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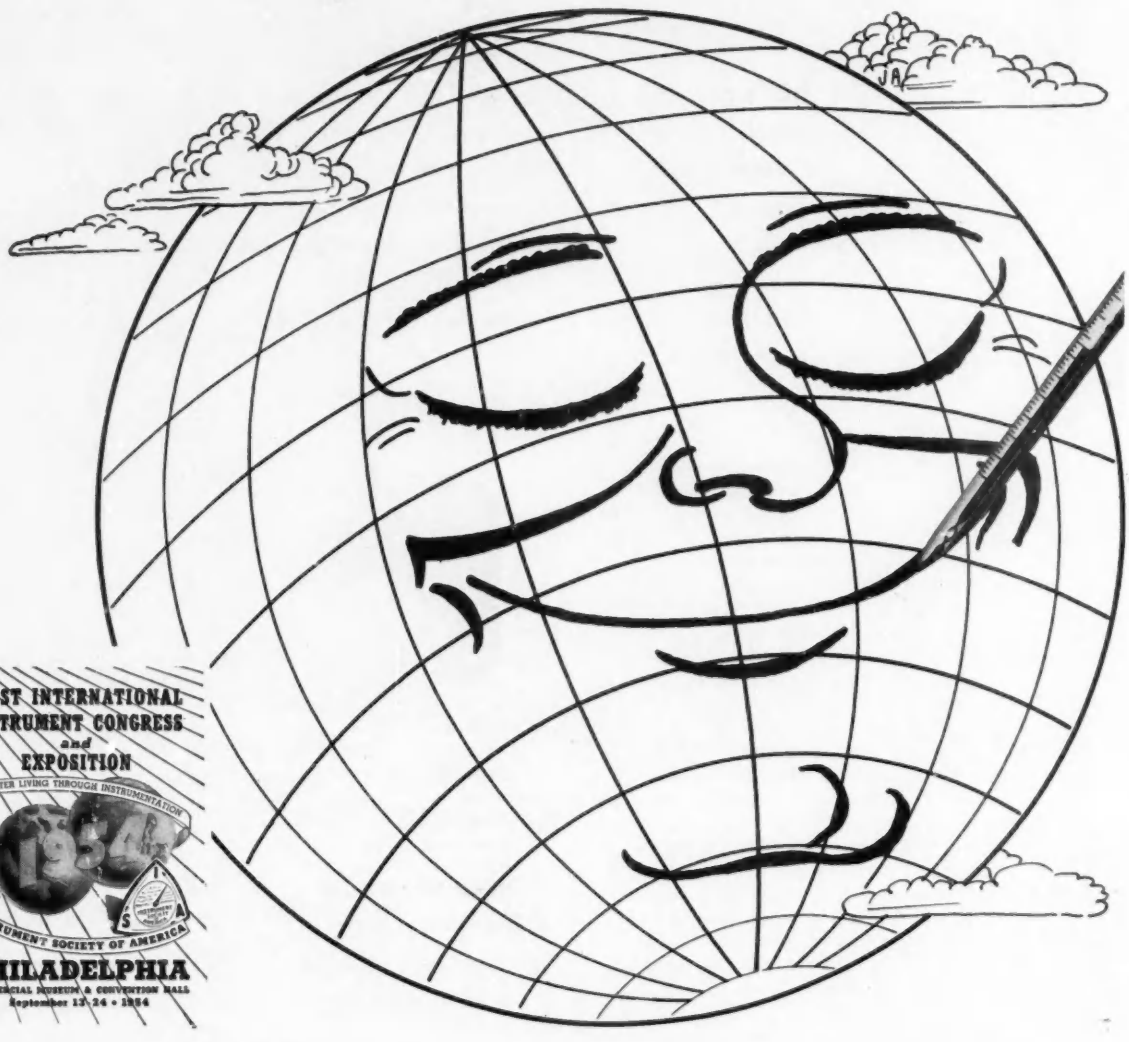
Taylor takes the



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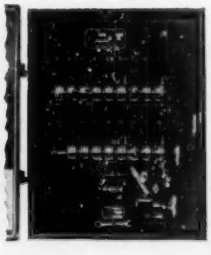

3. Automatic sequencing of batch operations. The Taylor FLEX-O-TIMER* Time Cycle Controller "does its own thinking"—takes care of as many as 36 operations automatically. Provides automatic timing of the sequence and duration of processing operations involving temperature, pressure, mechanical motion, electrical energy or combinations of each—precisely in accordance with a pre-determined schedule. Provides push-button operation for such jobs as: hydraulic press operation; batch charging and dumping; plastic molding operations; hydrogenation of edible oils and fats; dry ice molding; backwashing of catalyst and filter beds, etc.

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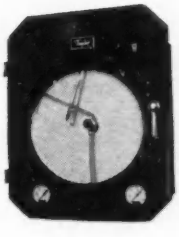
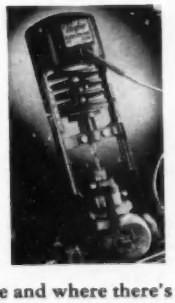
World's Temperature -

and that's not all . . . There are Taylor instruments for indicating, recording and controlling pressure, flow, liquid level, speed, load, density and humidity as well as temperature. We can supply you with a matched set of ASTM precision thermometers, or a completely-equipped graphic panel. And throughout the U. S. A., Canada, Australia, Europe, Latin America and many other parts of the world there are Taylor trained Field Engineers to help you with your instrumentation problems. Write for the name of your local man to Taylor Instrument Companies, Rochester, N. Y.

1. Graphic Panels requiring miniature instrumentation. The rapid advances of automation in recent years have necessitated the development of the graphic panel—and consequently miniature instrumentation. Taylor was one of the first in this field and the well known TRANSET* System carries many refinements of design based on actual field experience. For example, the need for more accurate measuring devices, due to separation of the functions of measurement and/or control and indication or recording, led to the use of the force-balance principle in transmitters. Thus the small power generated by minute changes of measurement can be transmitted with high accuracy to receivers. Taylor also contributed the TRANSET Plug-In Controllers and Receivers which reduce panel size, simplify mounting, mean fewer piping connections, easier maintenance and lower labor and material costs—*at no premium to you!*



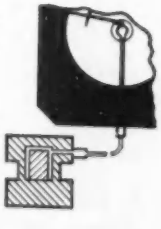
2. Complete local or point of measurement control. Fifteen years of unparalleled performance on all types of control problems have established the FULSCOPE* Controller as pre-eminent in accuracy, dependability and economy of operation. It is extremely versatile because the same control mechanisms are available for temperature, pressure, flow and liquid level—in either recording or indicating models, as locally mounted controllers, transmitters or controlling receivers. Interchangeable unit construction permits a small inventory of parts. Pre-calibrated units eliminate expensive checking. Easy accessibility means minimum down time. And the FULSCOPE Controller is adaptable to any control problem because of three control effects: Proportional Response, Automatic Reset Response, and PRE-ACT* Response (rate action) . . . another Taylor "first".



5. Dependable Non-Indicating Controllers for routine applications. The Taylor *Self-Acting Temperature Controller* (shown) is ideal for any process where air or electricity is not available and where "on the nose" control is not absolutely essential. Many ranges between 10° and 610°F. Can be used for valves up to 2"—direct or reverse acting.

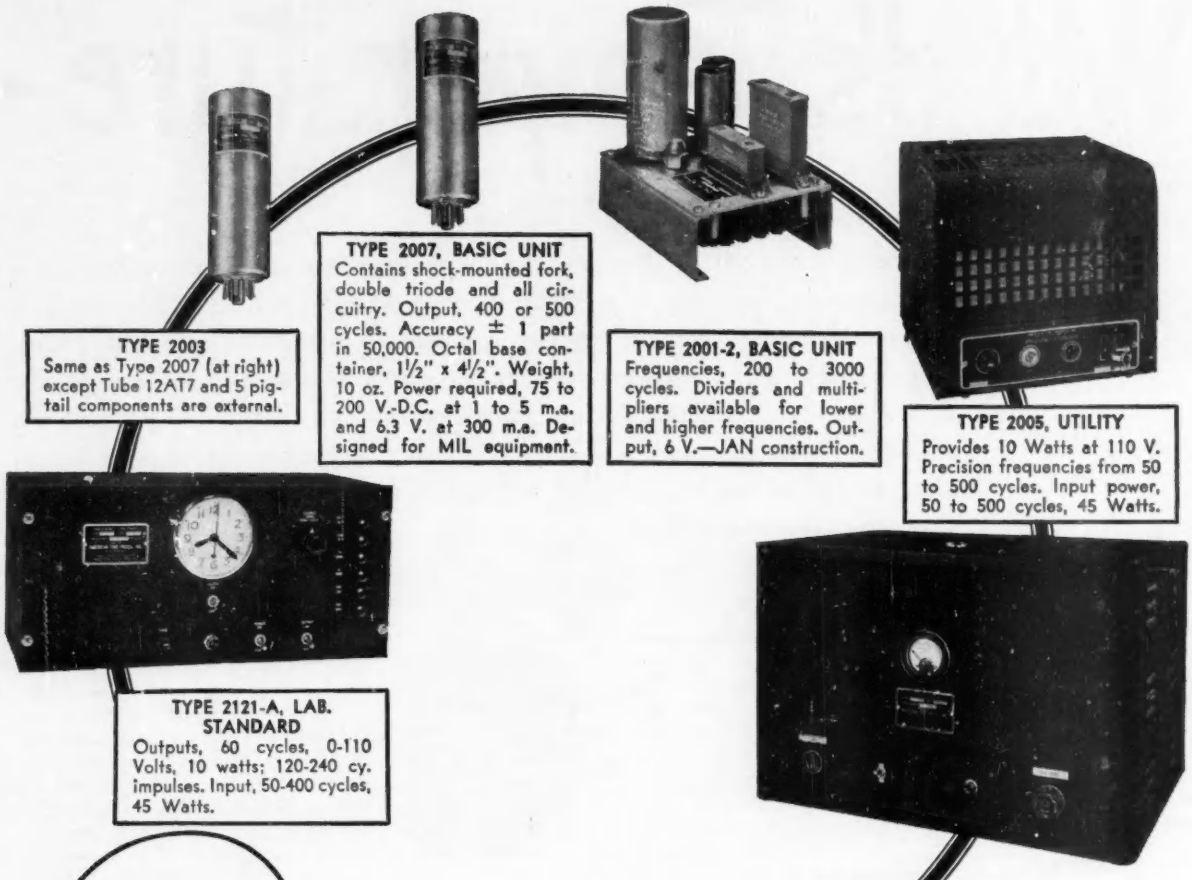
The Taylor Type-P *Expansion Stem Temperature Controller* is designed for applications where "on-off" control is acceptable and where there's space for the 12" or 15" rigid expansion stem. Air operated: control point easily changed.

For simple pressure applications the Taylor *10RF Non-Indicating Controller* is available in direct or reverse-acting types. Air operated; sturdily built; inexpensive.



6. Simple, economical measurement of load or force. Taylor Volumetric Load Measuring Elements are rugged, self-contained units for measuring force *directly* on the chart or scale of a recording or indicating instrument. No auxiliary source of power is required. This is one of the simplest methods of determining tension, compression loads and combinations or both on most any type of equipment. The paper and textile industries have proved their design, accuracy and performance over many years, and recent developments have extended their utility to many other applications such as: measuring tension on conveyor belts; film tension; thrust on bearings; forces applied by pneumatic or hydraulic cylinders on squeeze rolls; weight of suspended solids or corrosive liquids in tanks, and force applied on testing apparatus.

Taylor Instruments MEAN ACCURACY FIRST



TYPE 2003
Same as Type 2007 (at right) except Tube 12AT7 and 5 pigtail components are external.

TYPE 2007, BASIC UNIT
Contains shock-mounted fork, double triode and all circuitry. Output, 400 or 500 cycles. Accuracy ± 1 part in 50,000. Octal base container, 1½" x 4½". Weight, 10 oz. Power required, 75 to 200 V.-D.C. at 1 to 5 m.a. and 6.3 V. at 300 m.a. Designed for MIL equipment.

TYPE 2001-2, BASIC UNIT
Frequencies, 200 to 3000 cycles. Dividers and multipliers available for lower and higher frequencies. Output, 6 V.—JAN construction.

TYPE 2005, UTILITY
Provides 10 Watts at 110 V. Precision frequencies from 50 to 500 cycles. Input power, 50 to 500 cycles, 45 Watts.

TYPE 2121-A, LAB. STANDARD
Outputs, 60 cycles, 0-110 Volts, 10 watts; 120-240 cy. impulses. Input, 50-400 cycles, 45 Watts.

TYPE 2111A, POWER UNIT
50 Watt output. 0-110-220 V. at 60 cycles or any frequency 50 to 1000 cycles.

Precision FREQUENCIES

GUARANTEED ACCURACY
1 PART IN 100,000 (.001%)
except where otherwise noted

The basis of these frequency standards is an electronically actuated high-precision fork, temperature-compensated and hermetically sealed against barometric changes. The partial list of uses at the right not only suggests the broad range of applications but also proven dependability where there can be no compromise with accuracy. Please request details by Type No. Our engineers are available for advice or cooperation on related problems.

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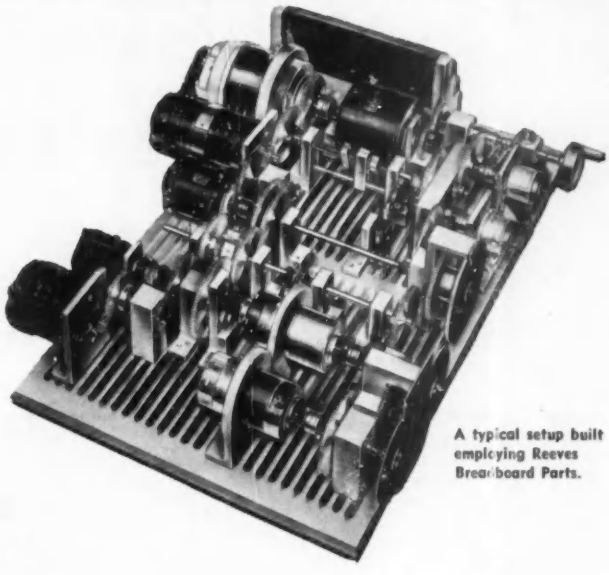

A typical setup built employing Reeves Breadboard Parts.

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ELIMINATE DESIGN TIME—

Reeves Breadboard Parts are so versatile that most types of high precision equipment such as servomechanisms, control devices and computers can be developed without designing and fabricating special parts.

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Slotted mounting plates, shaft hangers and component hangers give the Reeves breadboard method of assembly its speed and versatility. Components can be mounted quickly and easily in any desired position.

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Reeves Breadboard Parts eliminate the enormous waste incident to making modifications of experimental models built with special parts.

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Reeves Breadboard Parts are available in STANDARD (¼" shaft) and MINIATURE (⅛" shaft) sizes. The latter are ideal for applications where small size and light weight are important factors.

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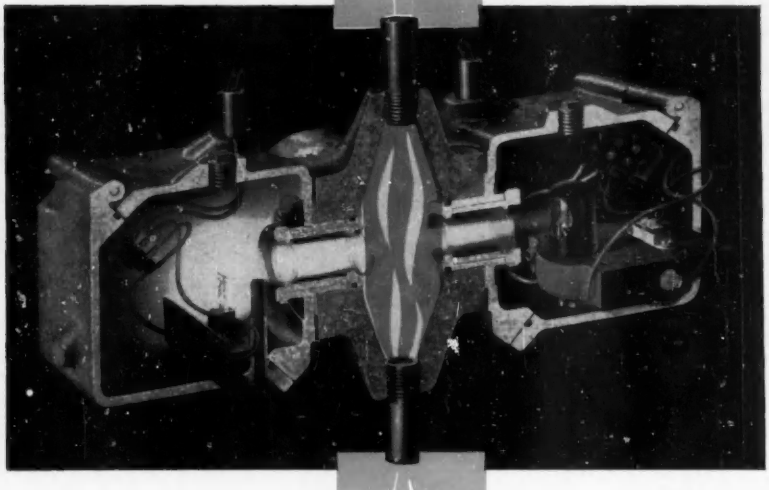

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Turbidity Color

in plant streams

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SOURCE A tungsten lamp is the radiation source. Filters select the color of light beamed through the flow cell.

FLOW CELL A stainless-steel casting with windows of ultraviolet-transmitting corex glass handles flows to 7 gpm, pressures to 150 psi. Flow cells can also be glass-lined or made specially from nickel alloys, plastic, etc. Path length can be 1, 2, or 5 centimeters. Openings provide ready access to inside of cell.

RECEIVER A sensitive phototube and exceptionally stable Beckman a-c amplifier measure the radiation transmitted through the flow cell. The amplified signal operates a standard potentiometer recorder. Amplifier circuit components are mounted in three separate plug-in units for immediate on-stream maintenance by regular operating personnel.

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- monitoring suspended solids
- monitoring nonmiscible drops suspended in a liquid
- determining color intensity

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Industry's Pulse

Pity the ambitious technician who wants to study up on control engineering. He borrows a couple of standard texts and wades in. Almost immediately he runs into a wall—a barrier of words. The engineers who have roused his interest in the subject and the authors of both texts are all speaking different languages. His enterprise squelched, the poor technician abandons his program of self-improvement. If his is a sensitive nature, he may flee to a job in a bakery, where flour is flour, dough is dough, and an oven is unambiguously an oven.

Tower of Babel

The sad fact is that the man who would keep up with control engineering today must be, to a great extent, multilingual. The concept and practice of automatic control has many roots, which are only now merging into a main stem. Engineers who entered this field by way of the process industries tend to think and talk in terms of valves, nozzles, and other hardware. Those who made their approach through servomechanism theory modulate their speech with the dynamics of components and systems.

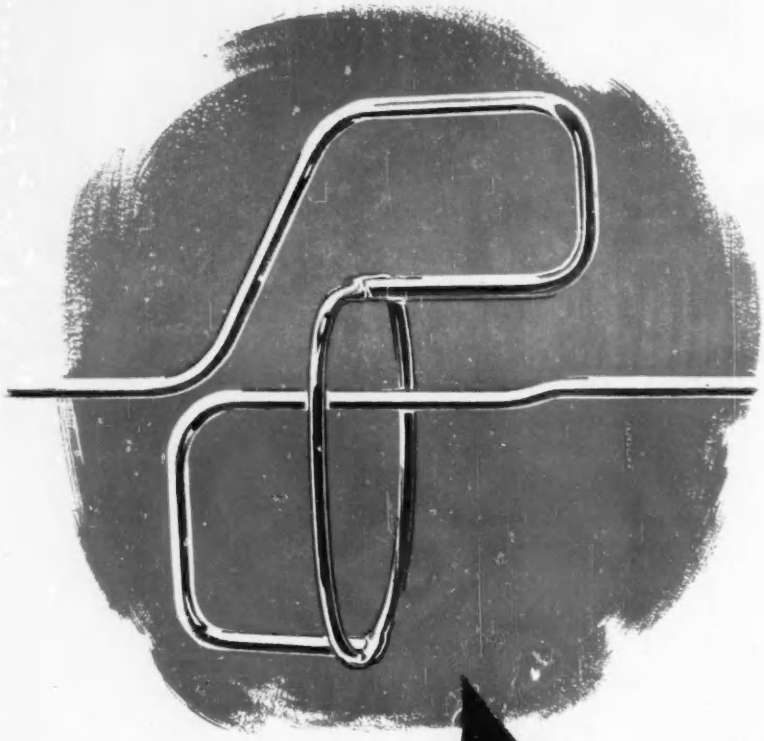
Several dialects and dozens of pet terms introduced by various experts further muddy the linguistic stream. So horrendous is the semantic confusion that a speaker at a recent meeting on automatic control complained afterward that he could hardly fathom the two papers preceding and following his own.

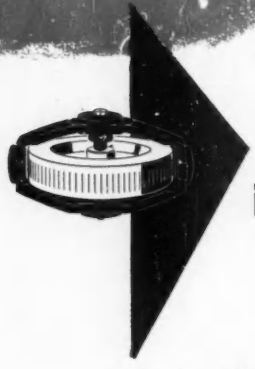
Meeting of Minds

Fortunately, control engineering has its own lexicographers. With remarkable patience, these few men have been defining a language common to all approaches to their field. In the United States to date the most comprehensive results have come from two groups: the Terminology Committee of the Instruments and Regulators Division, American Society of Mechanical Engineers, and the Subcommittee on Terminology and Nomenclature of the Feedback Control Systems Committee, American Institute of Electrical Engineers.

The ASME has been laboring at the language problem for eleven years; the AIEE for five. Their latest proposals, released last June and April respectively, are reassuringly similar .

First, the committees agree that the performance of all control systems can be discussed in terms of a simple and basic block diagram. Whether the system is a gun pointer or a petroleum fraction-





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When the gyro is precessed by rotating the pretzel about the axis of flow, it produces a torque. The torque produced by this precession is directly proportional to the mass flow of the material flowing through the pipe.

The ability to achieve greater simplicity, accuracy and dependability through the application of new engineering techniques has established NORWOOD CONTROLS as a leader in the fields of flow, pressure, temperature and weight measurment.

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ating tower, the same concepts apply.

The committees are likewise in full accord on the symbols they use to label parts of the block diagram. With a charitable attitude toward typist and printer, they have stuck to the English alphabet. The thetas, indicative of rotary motion, suit servomechanism thinking. But they don't apply generally to all means of control. So, they had to go. Other taboo letters were "d", which might be confused with differential, and the operators "s" and "p".

Agreement on specific terms is less close. But for fifteen basic words, most relating to the block diagram, the committees have essentially identical definitions. Each term applies to all the jobs that automatic controls can handle. "Error," for example, is a descriptive word in the discussion of servomechanism positioning. But it is inappropriate to the control of fluid flow in a chemical plant. Here, both committees endorse "actuating signal" to label the force that directs a controller to take action.

A standard terminology is in sight. The American Standards Association is now setting up a committee to write the dictionary of automatic control. The committee will draw representatives from some thirty or forty technical societies, government bureaus, and industry groups. With each member organization having, in effect, one vote, progress may be slow. But the very breadth of the consensus should produce a readily accepted standard.

The men who have been wrestling with the terminology problem for years cautiously avoid predicting when the ASA committee will finish its task. It may well be ten years before every term and symbol is settled upon. Even if standardization takes somewhat longer, control engineers will have a decided edge over mathematicians, who pride themselves on logical and unambiguous thinking. Almost three centuries ago, Sir Isaac Newton and Baron Gottfried Wilhelm von Leibniz independently developed differential calculus. Each, naturally, had his own symbol for the derivative of a function. Did their followers standardize? Indeed not. With high disdain for the universality of their language, they created a whole family of symbols, all meaning one and the same thing.

OUR POLICY: Much as they would like to, the editors of CONTROL ENGINEERING will not attempt to specify the terminology that will be used in this magazine. For the time being, CONTROL ENGINEERING will follow ASME and AIEE proposed standards wherever they agree. And when the new ASA committee finally promulgates its standard, this magazine will adopt it as the universal language of automatic control.

Common Ground

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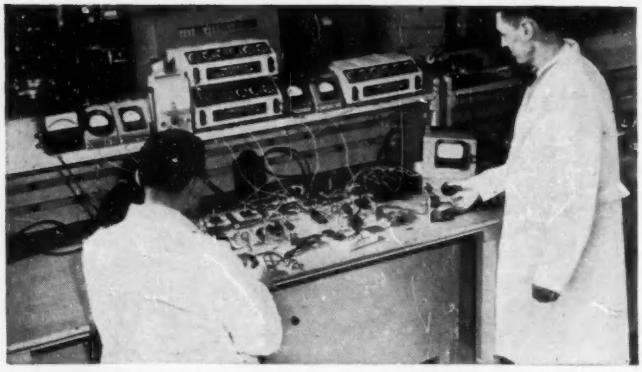

Ketay leadership is the result of sound, imaginative engineering. From the design of a specialized component to the fabrication of complete systems, Ketay engineers create the "standards of tomorrow".

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. . . leader in the development and manufacture of Synchros, Servo Motors, Resolvers, Amplifiers, Airborne instruments, and Automatic Controls.

Ketay leadership is the result of a combination of research, experience, and outstanding manufacturing facilities. Some of these facilities are pictured here.

Ketay has produced many *firsts* in automatic controls. For example, in Synchros, Ketay was first to produce miniaturized Synchros so remarkable for their high accuracy and unmatched reliability. Ketay was *first* to produce high temperature and corrosion resistant Synchros.

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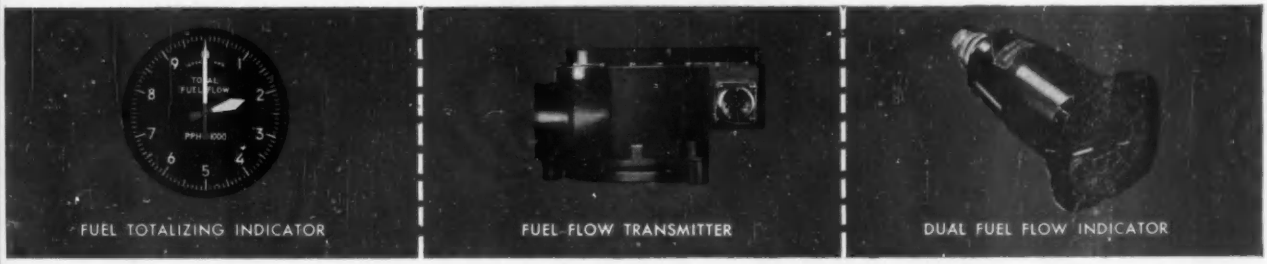

Electronic control devices are among the many instruments Ketay manufactures for aircraft, missiles, marine, ordnance, and civilian application. Special designs to meet the limitations of space and operating conditions.

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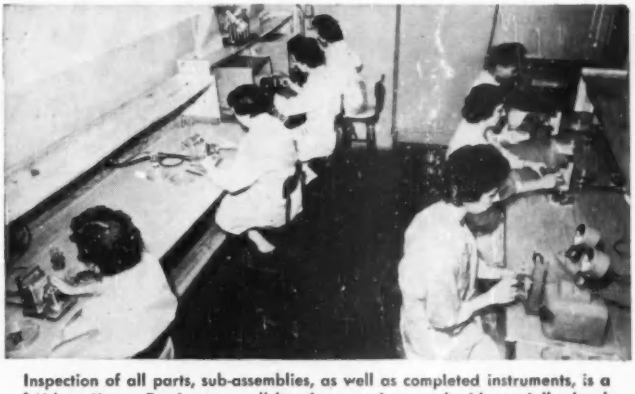

Inspection of all parts, sub-assemblies, as well as completed instruments, is a fetish at Ketay. For instance, all bearings are inspected with specially developed equipment in air conditioned work space. This is just one of the many techniques that assure maximum performance when Ketay units are specified.

electro-mechanical devices some of which are illustrated on these pages. Currently, original Ketay developments are providing instrument performance far above present standards—many of which were set by earlier Ketay developments.

Ketay successfully applies its production facilities and experienced research personnel to specific problems for the leaders in automatic control.

Your interest will be well served by learning fully of the products and services you may obtain from Ketay.

Write, today, for descriptive specifications of those types of Ketay instruments which may be applied to your designs.

Precision of manufacture is vital in every Ketay unit. To assure continuing reliability for its products, Ketay employs the very latest facilities and techniques. Typical is this "gear room" where modern gear cutting machinery produces gears to the finest of tolerances.

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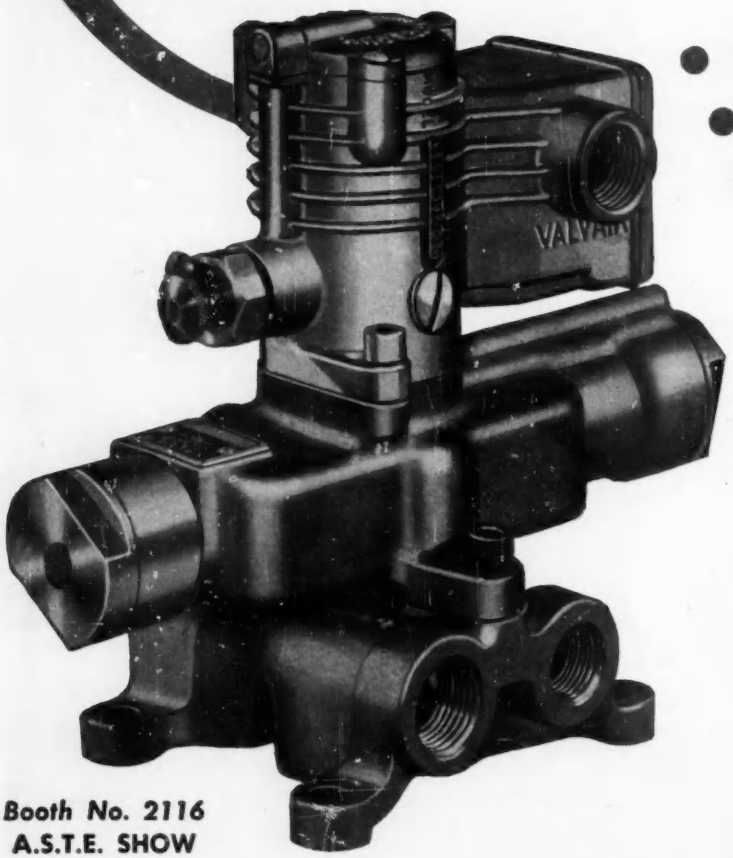

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Control
ENGINEERING
SEPTEMBER 1954

The Common Denominator

ONE of our editors attended a recent technical society meeting. While in a committee gathering, he looked around at his associates. They were all control engineers. But each had come from a different background. Their training was in physics; mathematics, electronics; chemical engineering, and mechanical engineering.

What brought these engineers together? A common denominator: the concept and application of automatic control.

Up to now the control engineer has not had a magazine of his own. He has had to scavenge through a dozen or more periodicals in hope of finding an occasional article aimed directly at him. The editors of CONTROL ENGINEERING are commissioned to remedy this situation. From our field we will gather fresh knowledge, integrate it, and transmit it to our fellow control engineers.

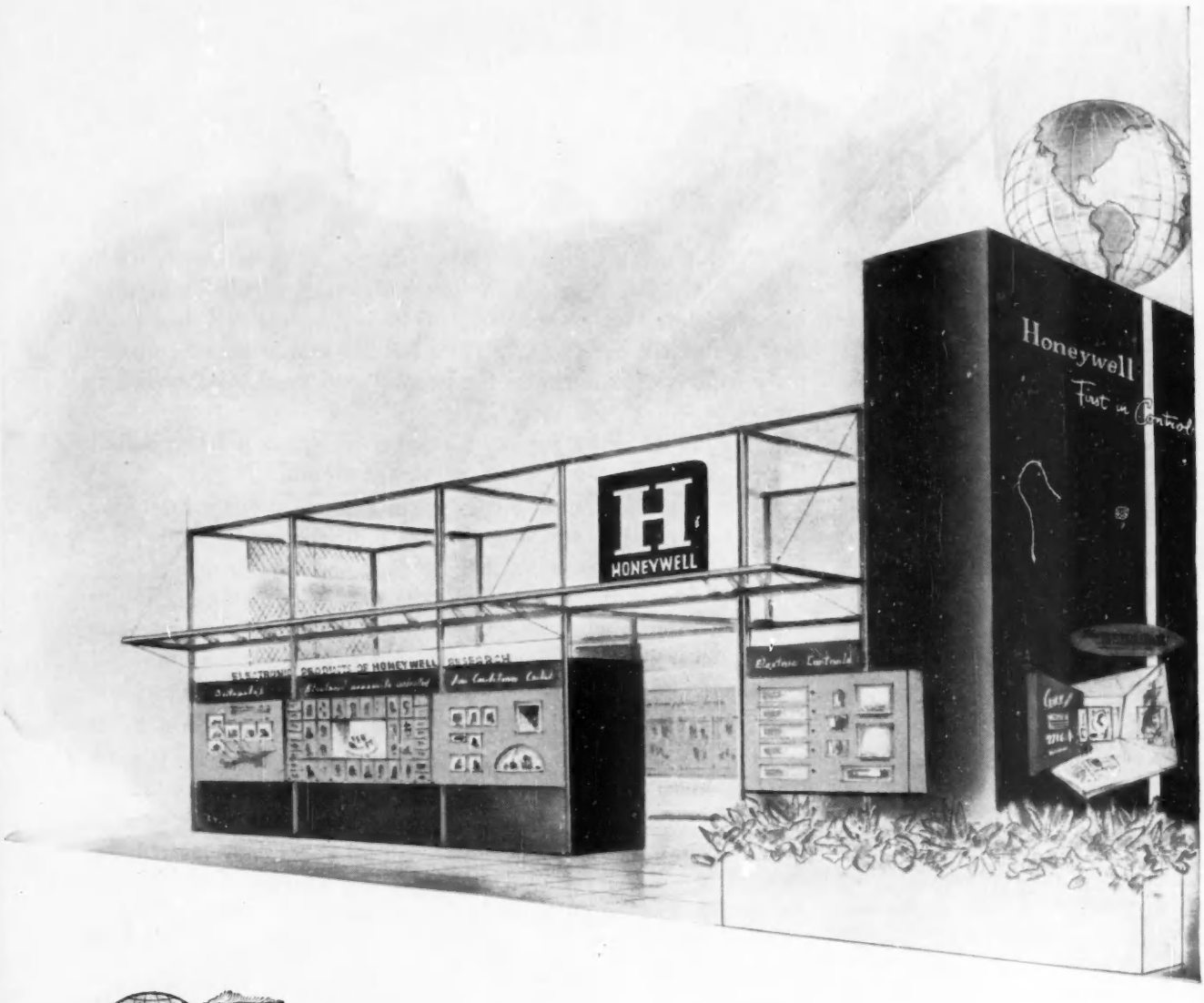
The engineer who creates control systems and keeps them working is a practical man. He realizes that a control system is not just an exquisite mechanism constructed to delight its designer. It must pay out. Management has a decision to make—to buy or not to buy, to build or not to build. It is the engineer's responsibility to provide the information for the decision. He must impartially present the economics of each case so succinctly that management's decision is simple. To aid the engineer in this extremely important phase of his work, we will cover the economic, as well as the purely technical, considerations involved in the engineering of control systems.

Many of the men we serve became control engineers without benefit of well rounded training in control theory. They have practiced their profession empirically. Because they want to learn the basic theories, we will carry review articles that relate theory to practice—to show that practice is theory at work.

The profession we represent is not static. The prophet and pioneer play an important part in its dynamics. Their ideas may become the foundation for tomorrow's advances. Their message will be a part of our magazine.

This magazine is a feedback control system. In a field as fluid as ours, we must continually measure the response to our efforts. The reader is our measuring element. We welcome his comments on all phases of our process.

THE EDITORS



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Whether your specific interest lies in industrial process controls . . . instrumentation to aid research . . . controls for heating and air conditioning of commercial and institutional buildings . . . aeronautical controls and instruments . . . you'll find products of Honeywell research that are applicable to your problems. The latest developments in *ElectroniK*, pneumatic and mechanical instruments—electric and pneumatic control systems—flow meters—pyrometer supplies and many related products—all will be shown in operating exhibits and informative displays.

Of particular interest to visitors from abroad will be the exhibit of Honeywell's extensive International Division, manned by specialists from overseas offices.

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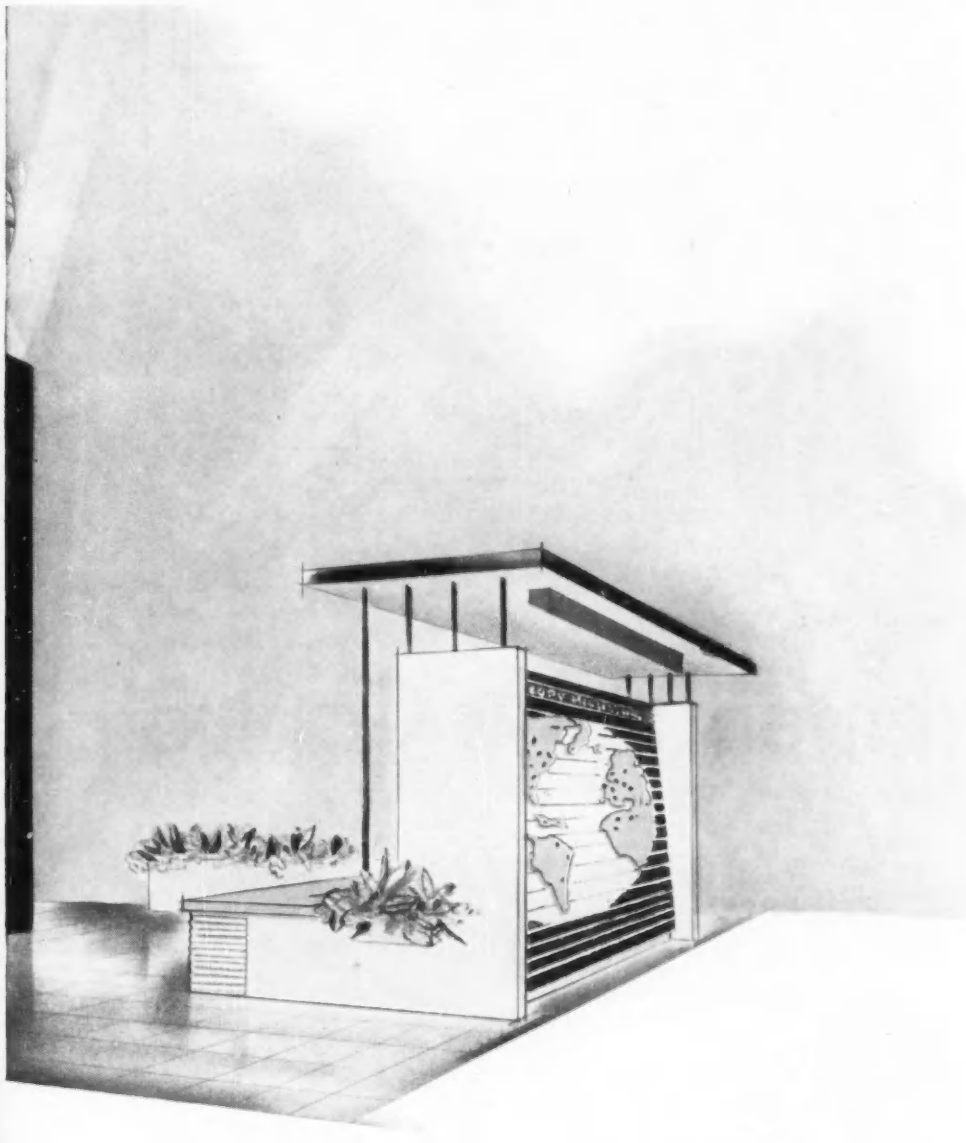

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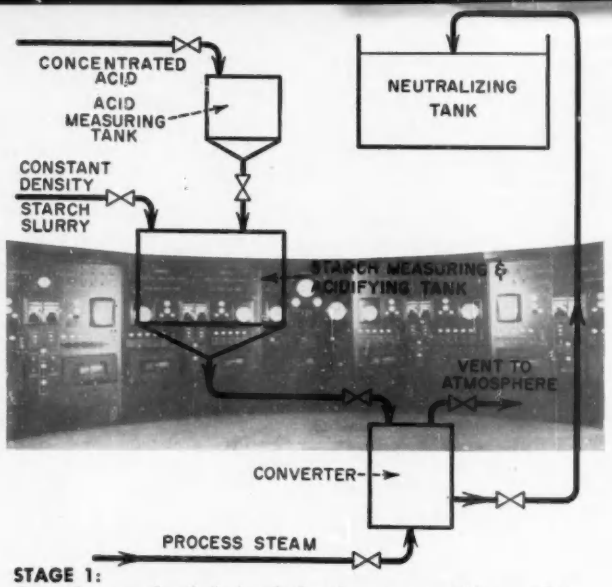
GROWING CONCEPT . . .

Economy, efficiency, and higher plant morale have been the payoffs of control engineering at Corn Products Refining Co.



STAGE 1:
Complex panel ruled simple batch process at Kansas City

INDUSTRIAL PROGRESS STORY:

Management Buys Control

H. C. FROST, Corn Products Refining Co.

TODAY no engineer undertakes a project at Corn Products Refining Co. without first determining the maximum benefits that can be realized through automatic control.

It was not always so. Back in the war years, company interest in this new engineering science was high. But the refining process still followed traditional lines, which appeared to create little opportunity for the devices and systems so well utilized in other process industries. Most major units produced batch by batch, and the obvious automatic controls seemed too complex or too expensive an addendum to the human operator who had to be on hand anyway.

The company, nevertheless, was interested enough to employ a man schooled in automatic control to survey the possibilities.

From this modest step of hiring a control engineer, and through a sympathetic management which endorsed his early efforts and subsequent major projects of a growing staff, Corn Products has assimilated instrumentation to where it is now accepted as one of the important phases of engineering and operation within the company.

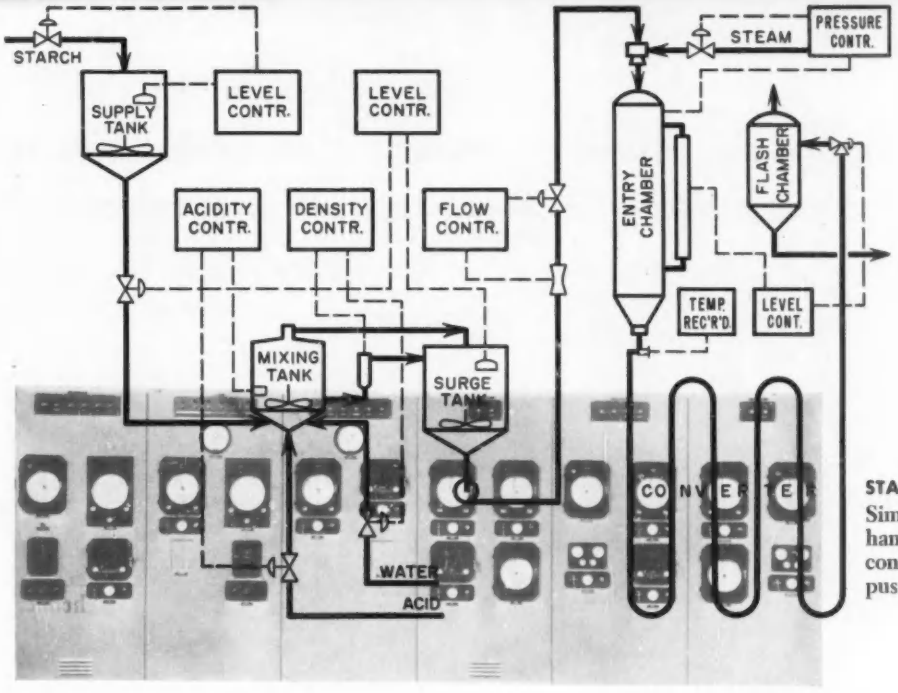
Because the progressive, historical aspects of the control program at Corn Products not only explain this company attitude but also frame a very interesting period of automatic control evolution, let us start at the beginning.

Getting started meant a practical demonstration of the advantages that were possible through instrumentation. At first, suggested applications were minor—the installation of a single recorder or temperature control.

At about this time, however, the company decided to renovate completely the corn sugar and syrup producing facilities at its North Kansas City plant. Even though this planning was well advanced, an opportunity was created for the control engineering group to study the proposed process and determine where automatic controls might be applied.

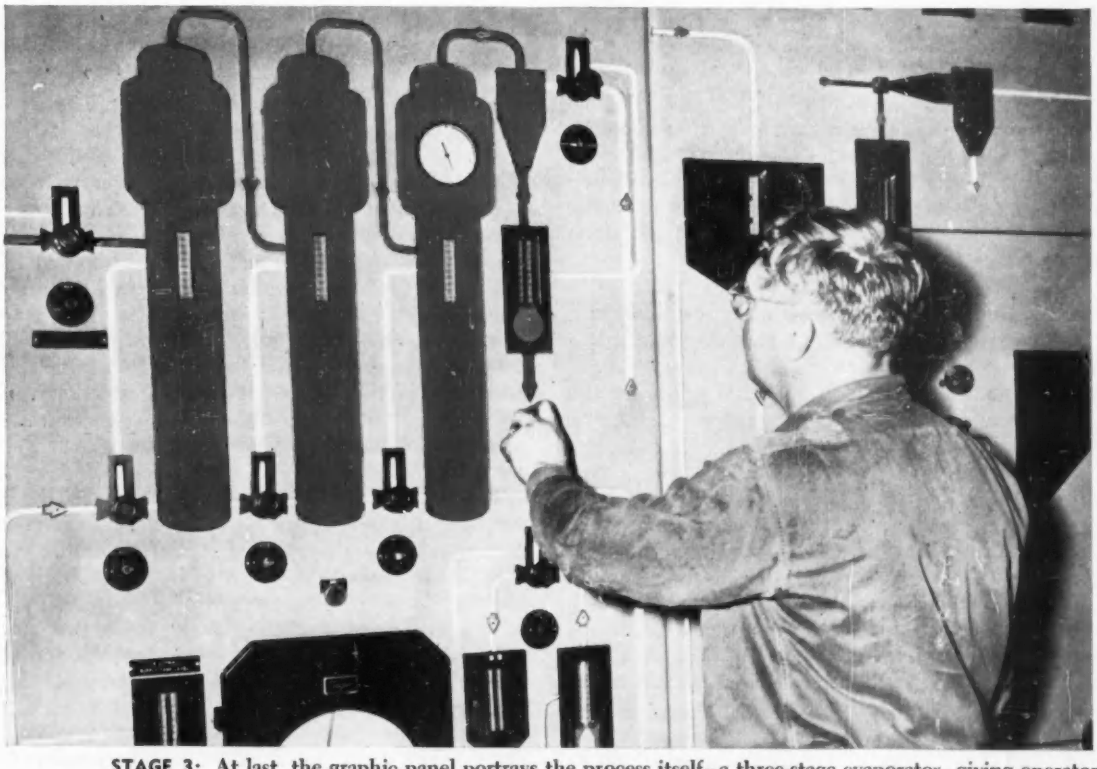
Essentially, the new process for converting starch to sugar and syrup was a sequenced batch operation, with material flow and scheduling under manual control. Analysis of the problem showed that a series of integrated closed-loop systems would simulate this sequencing and that the whole operation could actually be placed under central "one-knob control."* In addition to the sequence and time cycle control system for the converting operation, and the control systems applied to important concentration variables, it became apparent that a real contribution could be made in the succeeding steps of the process by controlling levels in tanks, so that capacities would match disturbances created

* A complete discussion of the Kansas City project was made by C. F. Adeszko in Paper 50-2-1, presented to the Instrument Society of America in September 1950 and published in the "ISA Journal" Vol. 7, No. 2, February 1951.



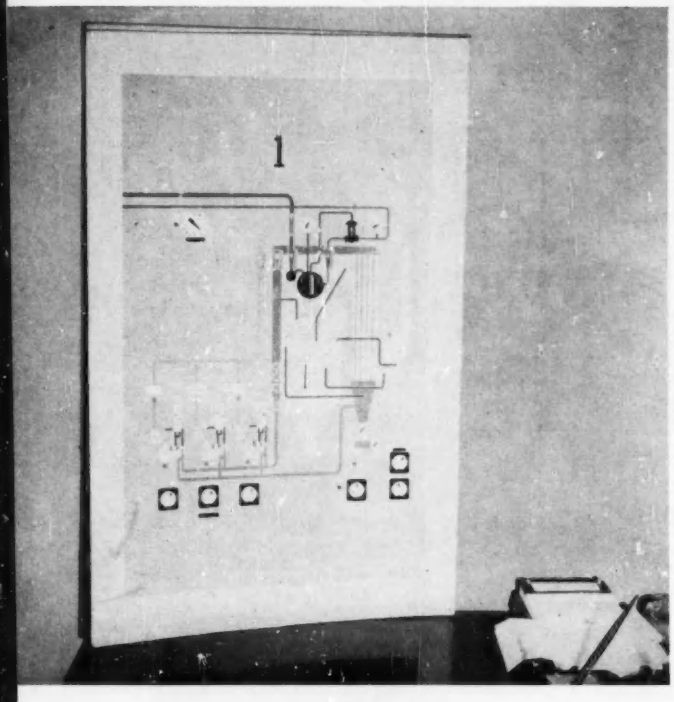
STAGE 2: Simplified instrumentation handled more complex continuous milling at Corpus Christi

Engineering



STAGE 3: At last, the graphic panel portrays the process itself—a three-stage evaporator—giving operator a feel for his job, a better understanding of the process, and a reassuring sense of participation

"Coupling this graphic presentation of the project with an economic analysis proved an excellent approach to management."



THE MEANS . . .

This is the scale-model panel which helped Corn Products management envision how easy and advantageous it would be to control boilers by the graphic technique. Today this unorthodox approach to power control nears reality in the Argo boiler plant, where one man will quietly oversee dynamics of six huge steam generators.

by the batch operations and other interruptions.

Convincing management to provide some major financing (approximately $160,000) for what it could only see as a gamble took a special effort by the control group. This consisted of dramatizing the proposed instrumentation in a simplified, batch-by-batch diagrammatic presentation. Thus it was possible to lead the unschooled viewer through each step of the automatic operation and show how certain concentration measurements could actuate control and how integrated operation was possible.

Coupling this graphic presentation of the project with an economic analysis of its benefits proved an excellent approach to management. This pattern of "selling" control has been followed whenever necessary. The technique of presenting just enough information on how the controls could accomplish their stated functions in an easy to grasp manner, with concise and forceful statements of expected benefits and savings, has played an important part in gaining acceptance of plans for making major control installations.

During the early phases of construction at Kansas City the company decided to erect a complete processing plant in Corpus Christi, Texas. Pilot plant work on a continuous converting and refining process for producing sugar had shown promising results, and it was decided that production here would be fully continuous.

Once again, almost visionary support by management was needed for a hypothetical and costly control project. For in addition to continuous conversion instrumentation, many other portions of the company's processing were analyzed from the control standpoint for the first time—and findings here were designed into the Corpus system. Further, the decision to make the investment was made prior to actual results from the Kansas City installation which went on-stream in the fall of 1948.

System design for Corpus Christi required a completely new approach by the control group. Control modes had to be more versatile to handle the moving process stream, and new measuring techniques had to be developed to measure directly the chemical and physical properties of the product.

Optimizing Control

Success of the Corpus Christi installation was evident almost immediately after start-up early in 1949. Here, for the first time in one of the company's plants, a complete process was conducted at optimum from a remote room without operator access to equipment.

But when the control engineering group had left and plant operators were on their own, high hopes were shaken. Evaluation after a few months of operation indicated several plant areas where potential gains were not being realized. In particular it was obvious that process operators were having a hard time translating measured information into action which would produce maximum benefit from the control system.

Here a basic error in thinking was revealed. In keeping with the times, design of the installation had been made using conventional dial indicators and round-chart records, coupled mainly with both remote and local automatic controls. Study of usage of instrument devices on the panels showed that most attendants had difficulty in relating pen and pointer movements to actual dynamics of the processes they were trying to operate.

In other words, we were faced with the uncomfortable fact that our automatic control installation had been ideally designed from the viewpoint of

the instrument or process engineer, but not for the plant operator who had to make it work. It seemed possible that a similar error was prevalent since this installation was similar to many others throughout industry.

Thus loomed the basic question as to what might be done to change the accepted philosophy of automatic control application. Should the system be designed to permit easiest interpretation by the operator—even at the expense of education and experience, which instrument engineers and designers had so long believed important? Further, wouldn't manual process operators facing automatic control in the other plants have even more difficulty than the Corpus Christi men since they had to forget an old method of operation as well as learn a new one?

Obviously the process attendant was really concerned and interested in the plant equipment he had to operate. Hence a working solution might be to confront this operator with a flow-diagram of his process superimposed on the controls.

Enter Graphics

Using this basic idea a unique small installation was designed for the Pekin, Illinois, plant in which information shown to the operator was almost fully submerged in an outline of the process on the panel. True, other companies were also experimenting with the graphic approach at the time. But this Pekin system, we believe, went considerably further in its attempt to completely reorient the thinking of the designer to the practical needs of the operator.

To carry out our concept, we had to design several specialized, unusually compact instruments and devices to fit the panel space. These were applied to show relation to the process, with minor controls hidden from the operator and important ones brought out in bold relief on the process diagram.

This first graphic panel controlled a triple-effect evaporator. The operator—a veteran who had manually controlled the same equipment for 15 years now had to look at this new panel remote from the evaporator and attempt to run it. As it turned out, just thirty minutes of instruction at the board were enough to permit this operator to duplicate and exceed his past performance in the plant.

Results with this initial Pekin panel were so encouraging that all five evaporating sets were placed under similar control. As had been anticipated, one man could easily operate all five evaporators. Closer operating tolerances and a sizable reduction in down-time resulted from the new system.

Perhaps the most rewarding aspect of the graphic development, however, has been the drastic shortening of the training periods for operators.

Since the Pekin evaporator installation, the graphic technique has been explored and exploited on a variety of processes within the company and has met with success in every case. In recent years this program has been greatly implemented by the many new miniature components offered by instrument manufacturers.

THE MAN . . .

Author Frost learned his engineering at Toledo University, then got into the control field with Leeds and Northrup in 1937. He joined Corn Products in 1945 to develop a broad company instrumentation program. In 1948 he became Head of Engineering Planning, and last year was made Assistant Chief Engineer.

New Concepts

Experience with graphic panels has generated interest in improved control in other than process areas in the plant. Recently, for example, a graphic approach has been applied in the sizeable boiler plant at Argo.* This system has just started to operate.

* Details of this control installation will be presented in a paper, "New Concept of Control for a Steam Generating Plant," by R. S. King to be given at the ISA annual meeting in Philadelphia in September.

Eventually, it is expected, a single attendant will run a bank of six 250,000-lb-per-hr boilers from one central point.

The decision to explore this unusual mode of boiler control actually stemmed from experience gained from a conventional control installation on two of the units a few years before. At that time

each boiler had its own control panel and a single operator. The control stations were in a noisy, hot area which induced personnel turnover. Optimum control was hard to achieve with unschooled personnel.

A study of boiler operation by the control group suggested that, in so far as its control dynamics were concerned, steam generation was simply another process. Why not then view it as such in the control approach?

Actually, the design developed for a boiler graphic turned out to be somewhat different from the conventional process approach inasmuch as minute-to-minute boiler intelligence was put on panels, and actual controls on a console—both in front of the operator. Most of the recorded information was put on panels behind the operator. This segregation of recorders enabled one man in a central location to run all boilers without being encumbered with superfluous information. The chart records, of course, are invaluable in showing trends and for accounting.

In order to convince operating personnel that the new approach would be successful, a small scale model of the control room was made, and this was supplemented by blown-up scale models of the actual indicating panels. Thorough study of these models was enough to convince management that the cost of replacing existing conventional control equipment on the boilers could be "written off" in favor of the gains that would come.

A similar "fresh" look from the control standpoint is currently being given to many other normally unsuspect areas. For example, central stations for controlling materials handling and packaging are at this time under consideration.

Five Steps to Success

To all engineers who are putting an industrial process under automatic control author Frost recommends this five-point campaign plan:

- ▶ Make sure you fully understand the process.
- ▶ Avoid wasted effort by deciding beforehand what you want to control, how you want to control it, and what equipment you really need.
- ▶ Take time to explain the new controls to operating personnel so that they understand what the controls do and how to use them.
- ▶ Follow up your installation with inspection to make certain the controls function properly and to correct any flaws that may show up.
- ▶ Integrate process design and control system at an engineering level. You can't expect much benefit from merely hanging instruments on an existing process, like lights on a Christmas tree.

Behind the Panel

Prime mover in the company's control program today is an instrumentation group in the Central Engineering Department comprised of five graduate engineers all with backgrounds in control engineering. Members of this group have trained in chemical, mechanical, and electrical engineering—hence its make-up represents different research viewpoints. By working closely together, the men obtain both objective and functional solutions for each problem.

In the beginning only a few people at each plant were concerned with maintaining the relatively few devices then installed. And for the most part these were not separate organizations but merely part of other shops, such as electrical or mechanical maintenance. Needless to say, these individuals had little formal training in control and usually learned maintenance and "tuning in" the hard way.

The few control engineers hired by the company after the war came from both instrument makers and users, and at first they had to work closely in operations to learn about company processes. As this group started to make more and more installations, it became necessary to set up well-grounded instrument maintenance departments in each plant.

Instrument maintenance at a plant level has grown significantly to keep pace with the many and variegated devices employed. This growth, however, has been given careful study to be sure that maintenance costs were not excessive for the gains in view. To date, it can be safely said, the cost of instrument maintenance facilities—including equipment and manpower—has been a small part of the actual return from instrumentation.

Today's Planning

Now that solid values have been established, we occasionally find it necessary actually to combat overenthusiasm in operating personnel who visualize incredible gains in a blanket program of automatic control. Excessive instrumentation, of course, can be as detrimental as inadequate control. To hold this zeal at reasonable level, several groups within the company examine any proposed installation and judge whether it will produce significant savings and improvements.

Opportunities for applying control equipment result from studies of existing processes, planned modernization programs, and construction of new facilities. Each potential application is carefully studied to make sure that (1) the newest techniques are being employed, (2) the gain from the proposed expenditure justifies the cost, (3) the equipment can be installed so as to provide the desired results with operating personnel who will be assigned, (4) the maintenance costs will be reasonable, and (5) the installation will be in keeping with any long-range program for that particular area.

TROUBLE SHOOTING IN ADVANCE BY

Proper Wiring Design

GERALD WEISS, The W. L. Maxson Corp.

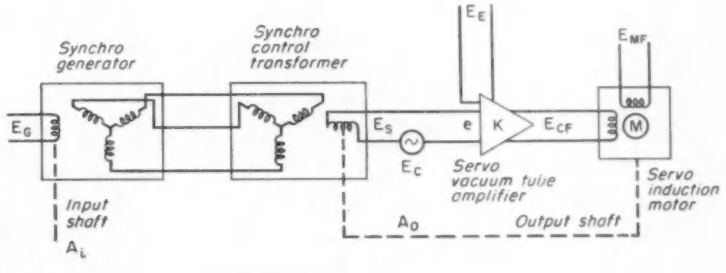
Inattention to wiring design is a common source of "bugs" that spoil otherwise expertly conceived control systems in the low frequency band between 60 and 1,000 cps. Here are some tips on how to avoid pitfalls by proper grounding, shielding and twisting.

ONE REASON for faulty wiring is that an engineer has a tendency to think of wiring as merely a line on a schematic diagram. Actually, a wire is a piece of equipment with mechanical and electrical properties. It has resistance, capacitance, and self-inductance; similarly, a group of wires exhibits mutual capacitance and mutual inductance. Like every other part of the system, wiring has to be designed. With proper design based on elementary electric circuit theory, most difficulties can be anticipated and prevented.

Today's control systems use arrays of closely packed complex electrical equipment. Alternating current systems predominate, with the size of com-

TROUBLE

Effect of Pickup on a Synchro Servo



THIS SERVO uses a two-phase induction motor as the servomotor, a synchro control transformer as the response element, and a vacuum-tube amplifier as the servo amplifier. The motor drives the control transformer to a position where the torque on the motor produced by voltages E_{MF} and E_{CF} is just equal to the friction load of the motor. At the equilibrium point the voltage E_S constitutes the static error of the servo. In the absence of pickup, if the friction load is zero or if the amplifier gain is infinite, the static error E_S is zero. For this example, assume the ideal conditions of zero friction load and zero static error.

To determine the effect of pickup, introduce a stray coupling voltage, E_C, into the input side of the amplifier. Four conditions of frequency and phase can characterize this stray voltage.

► IN-PHASE PICKUP—For this condition E_C has the same frequency as E_S and is in time phase with it. Thus E_C plus E_S equals e. The servo motor drives the control transformer to an equilibrium position where e equals zero. At that time the static error is no longer zero but equals minus E_C. For example, consider a 26-volt synchro with a gradient of 7.56 mv per min. With an in-phase pickup of 10 mv, the static error is 1.3 min.

► QUADRATURE PICKUP—The stray voltage, E_C, has the same frequency as E_S, and is in time quadrature with it. Assume the servo motor drives the control transformer to the angle where E_S equals 0. At that time the remaining E_{CF} is caused entirely by the quadrature pickup, E_C. There are two possibilities depending on whether E_{MF} is in exact time quadrature with E_S (assuming zero amplifier phase shift).

If E_{MF} and E_S are in exact time quadrature, then E_C and E_{MF} are in exact time phase. The servo motor cannot develop torque and the equilibrium is undisturbed. However, if the quadrature voltage is large enough, it will saturate the amplifier and reduce amplifier gain. This increases static error (in the presence of friction) and impairs dynamic performance. For example, a 26-volt motor is driven by an amplifier which saturates at 26-volt output and has a gain of 260. A total quadrature input of 100 mv will saturate this amplifier. Saturation also causes errors because of amplifier phase shift.

In the more usual condition, E_{MF} and E_S are not in exact time quadrature, but are out of phase by an angle B. The motor develops a torque and drives the control transformer off null. At the equilibrium position the static error, E_S, equal E_C tan B. Thus if B equals 10 deg., E_C equals 100 mv and the synchro gradient is 26 volts per radian, the resulting error is 2.3 min.

► HARMONIC PICKUP—If the frequency of E_C is a higher harmonic of the frequency of E_S, then harmonic pickup can cause amplifier saturation in this type servo. It may also produce a harmonic torque in conjunction with harmonic components in the main motor field excitation voltage, resulting in a static error. This error is usually negligible, as can be verified by calculation.

► MISCELLANEOUS PICKUP—Occasionally pickup is encountered that is of a frequency not related to the carrier or of a subharmonic frequency. This pickup again tends to cause amplifier saturation. The most serious difficulties arise when the frequency of the pickup voltage is close to the carrier frequency. The servomotor will then develop a torque pulsating at the beat frequency (the difference of the frequencies of E_{MF} and E_{CF}). For example, if the carrier frequency is 400 cps and the pickup frequency is 410 cps, the motor will develop a torque pulsating at 10 cps. This torque will cause the servo to oscillate at this frequency. Fig. 1.

Design Tips for Wiring

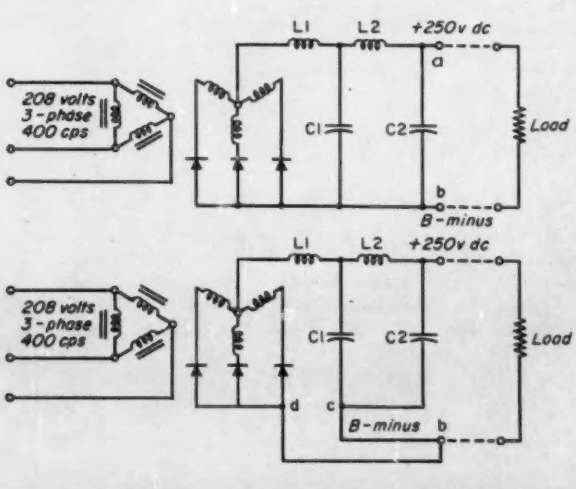
1. To avoid ground resistance coupling, the electrical design engineer should check for correct point-to-point wiring in addition to checking the correctness of the schematic diagram.

2. Proper grounding procedure requires that no circuit needs the chassis for continuity. The chassis should be a unipotential surface. For any one circuit, only one wire must be used for the tie to the chassis, since multiple connections cause ground loops and inductive pickup.

3. To prevent inductive pickup, reduce loop areas by twisting. This costs nothing and should be done regardless of the magnitude of possible sources of pickup.

4. To reduce capacitive pickup, shield the proper circuit elements. Indiscriminate shielding increases cost and capacitance and may do more harm than good. Possible pickup should be estimated numerically and only critical circuits shielded.

A schematic diagram does not necessarily show that resistive coupling may cause trouble. Point-to-point diagram, top, indicates that pickup can be prevented by removing lead bd and connecting c to d. Fig. 1



ponents reduced to such an extent that the wiring constitutes an appreciable percentage of the total weight and volume. Dozens of wires with different signal levels are crammed together. The techniques presented here pertain specifically to ac servos, computers, and similar electromechanical equipment; however, they also apply to a wide variety of other measurement and control systems operating off low frequency ac supplies.

In practice, a computer is carefully designed, built according to specifications, and then often found to be operating improperly. The static error of the servos is excessive, gain is low, and undesirable oscillations are observed. Measurements may show large quadrature and harmonic voltages, excessive power supply ripple, and zero offsets in electromechanical components (resolvers, synchros, potentiometers). When a recheck of the design shows no apparent errors, the trouble can usually be traced to pickup in the circuit wiring.

Pickup is a term for stray or unintentional coupling between circuits. By coupling is meant a voltage produced in one circuit because of a voltage or current in another circuit. Unintentional coupling is always unproductive and often harmful.

Some of the effects of pickup on system performance are illustrated in Figure 1. Here a simple synchro position servo is subjected to in-phase pickup, quadrature pickup and harmonic pickup. This example does not consider the source of the pickup voltage, the only object being to show the effect of the frequency and phase characteristics of the pickup on servo performance.

Other types of circuits will react differently to pickup, and as a system is builtup from many elements, there may be interaction between them. But regardless of the complexity of a system, the effects of pickup can be calculated. The basic considerations involved are enumerated in Figure 1.

The criteria for maximum allowable in-phase error, quadrature voltage, and harmonic voltage are set up. Components are selected whose characteristies fall within these allowable limits. Usually the component errors consume all of this allowance, and no tolerance remains to take care of pickup in the wiring. Then if the system is wired incorrectly and pickup is appreciable, the total allowable error is exceeded and system performance is unsatisfactory. Stray coupling can be divided into three classes: resistive, inductive, and capacitive.

Resistive Coupling and Grounding

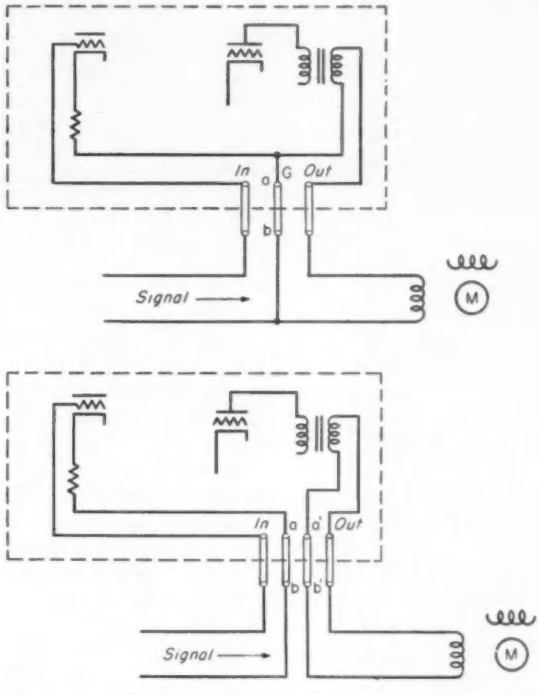
Resistive, or conductive, coupling occurs when several circuits are physically connected and share a common resistance. For example, when two vacuum tubes are supplied from the same *B-plus* supply, the power supply is common to both plate circuits. This

can result in the effect known as motorboating. There are various methods of decoupling the *B-plus* supplies, and motorboating can easily be prevented. Since resistive coupling can be recognized on a schematic diagram, troubles caused by this circuit arrangement should be rare. However, unintentional resistive coupling is actually encountered quite often, particularly in ground circuits.

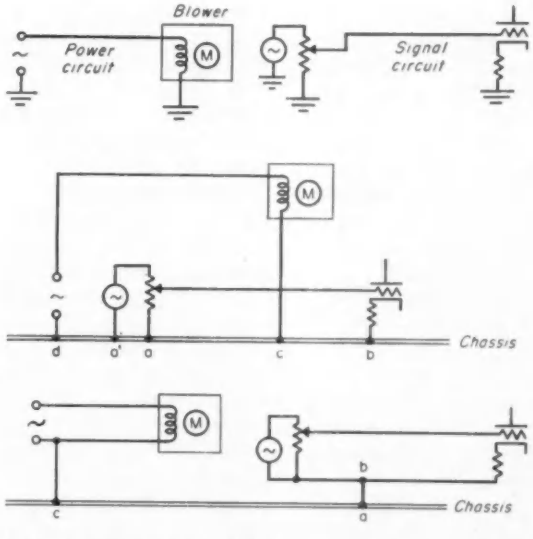
Three circuits involving unintentional resistive coupling are shown in Figures 2, 3, and 4. The circuit diagram of Figure 2) shows a 250-vdc power supply designed to operate off a 208-volt, 3-phase, 400-cps source. The allowable ac ripple was limited to 50 mv, and filter components *L1*, *C1*, *L2* and *C2* were designed accordingly. On assembly and test, excessive ripple in the 250-vdc supply caused trouble. When the power supply was isolated and the ripple voltage measured, it was found to be 250 mv or five times the allowable. To obtain more filtering, the capacitance C2 was increased. Instead of decreasing, the ripple increased. Examining the point-to-point wiring, it was found that the *B-minus* side (or ground side) was connected as shown in the lower part of Figure 2. The ac return current of the rectifiers, flowing through the resistance of wire *bc*, was adding ac ripple to the dc output. By removing wire *bd* and connecting *c* to *d*, the ripple voltage dropped from 250mv to less than 30mv.

Top of Figure 3 shows a plug-in amplifier for a 400 cps servo motor. The open loop gain of the amplifier was calculated to be at least 100,000. Prototype units indicated, however, that the gain was too low, ranging from 30,000 to 70,000. The trouble was traced to the connector. To save one connector pin, a common pin had been used for the ground return of both the input and the output. The output current through the contact resistance *ab* developed a voltage that was opposite in polarity to the input. This constituted negative feedback and caused a decrease in gain. The resistance varied from unit to unit, causing a variation in gain from amplifier to amplifier. When the connector was rewired, as shown in the lower part of Figure 3, the gain was satisfactory. Note that it is permissible to connect *a* to *a'*, or *b* to *b'*, but not both. No current must flow in the connection; it serves merely as an electrostatic tie.

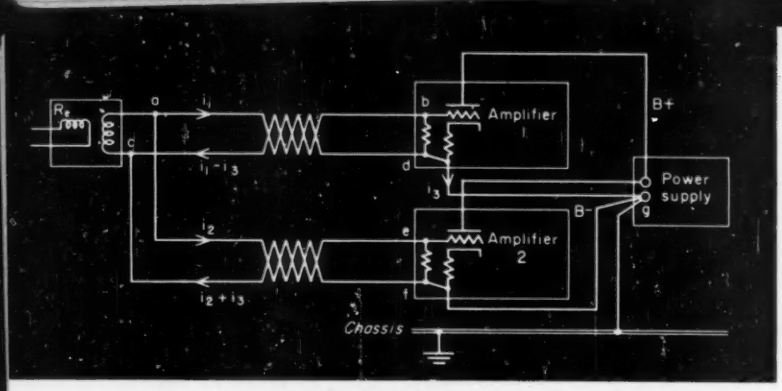
Figures 2 and 3 illustrate ground resistance coupling between the input and output of the same circuit. Another common situation is ground resistance coupling between two or more unrelated circuits. Figure 4 (top part) shows a power circuit and a signal circuit, both part of the same instrument. Their ground returns connect to the common chassis at different points. By redrawing the circuit, Figure 4 (middle), it can be seen that the two circuits share a common resistance, namely the chassis. The blower current causes a voltage drop *cd* in the chassis that is coupled into the signal circuit, resulting in incor-



Grounding of amplifier input and output through common connector reduces pin amplifier gain because of negative feedback to input. By grounding through separate pins, gain is not affected. Fig. 3



A signal and a power circuit are connected as shown in the middle diagram when they are assembled in an instrument. This causes pickup in signal circuit since the chassis is required for continuity. Proper grounding, shown at bottom, eliminates pickup since chassis serves as a unipotential electrostatic shield. Fig 4



GROUND Loop, and consequently pickup, resulting from interconnection of two circuits. Loop cdgfc is broken by removing lead fg. This causes some resistive coupling; however, this is not as undesirable as the ground loop, and can be made negligible by using sufficiently heavy wire for leads cd and dg. Fig. 6

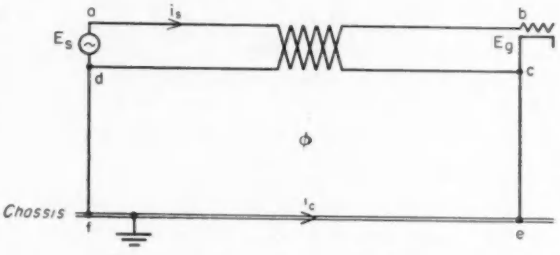
rect operation. The proper method of grounding is shown at the bottom of Figure 4. Here each circuit has its own return, with the low side of each circuit connected to the chassis at one point. No current flows in the chassis since the chassis serves merely as a unipotential electrostatic shield. Also no current flows in the ground wires *ab* and cd; they are merely electrostatic ties.

One of the major reasons for many of the problems involving resistive coupling is the lack of a clear definition of what constitutes a ground. For example, in a typical large airborne fire control system the following pieces of equipment were all called "ground".

- The frame of the airplane.
- The metal frame of the various boxes housing the fire control system.
- The neutral of the 3-phase, 400-cps aircraft supply.
- The negative side of the 28-vdc aircraft supply.
- The common of a 2-phase, 400-cps precision supply that was part of the system.
- The "low side" of the signal supply. This was the second phase of the 2-phase supply mentioned above, after passing through a filter and step-down transformer.
- The *B-minus* side of the computer power supply and the *B-minus* side of the radar power supply.
- The "low side" of more than a dozen signal and computing circuits, after passing through transformers, synchros, resolvers, or tachometers.

Electrical equipment is connected to earth to insure the safety of the operating personnel and to reduce proximity effects. Generally only one point of any given circuit can be exactly at earth potential; however, this point should be selected so that as much of the equipment as possible is close to earth potential. This can usually be accomplished, since most circuits are made up of cascaded T and π sections. These types of four-terminal networks have no series elements on one side (the "low side"). Therefore, this whole "low side" of the circuit is at approximately the same potential. One point on this side is then connected to earth, or grounded. If this is done incorrectly, coupling can result.

To avoid ground resistance coupling inside of a single circuit (as in Figures 2 and 3), care should be taken that no wires are unintentionally made common to both input and output.



TYPICAL GROUND LOOP caused by improper grounding. Loop area abcda is reduced to zero by twisting; however, loop area abefa still exists. Pick-up stops when either ground connection is removed. Fig. 5.

When a system contains several uncoupled electrical circuits, each circuit must be complete in itself and no circuit should require any portion of the chassis for continuity. One and only one point of each such circuit should be connected to the chassis by a single wire; in addition, the chassis should be connected to the earth or to the frame of the building or vehicle in which it is located.

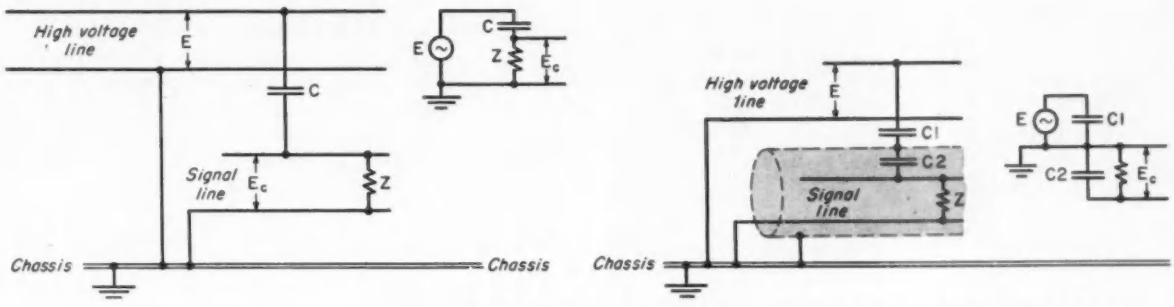
When coupling is unavoidable, for example, when two or more circuits must be connected together at their ground sides, no ground current should flow through the chassis, and the chassis must not be required for circuit continuity. In such applications, the wire size of the common ground leads should be large enough to keep the resulting IR drop at a negligible value. Paralleling ground leads may help, but care must be taken to avoid "ground loops," as discussed later.

Where an instrument has more than one electrostatic tie to the chassis, all ties should be run to the same point on the chassis. This guards against circulating chassis currents and ensures a uniform chassis potential. The electrostatic ties should be easily removable to facilitate trouble-shooting.

Inductive Coupling and Ground Loops

When a closed electrical loop is placed in a magnetic field, a voltage is induced in this loop equal to

$$e = -\frac{d\varphi}{dt} \qquad (1)$$



THE MUTUAL CAPACITANCE between two wires, (left), causes pickup voltage E_c to be induced in the signal line as a result of the proximity of the high voltage line. This pickup can be prevented by wider spacing of the wires and by proper shielding, (right). Fig. 7

where ϕ is the total flux linking the loop. If the flux density is B, the voltage is

$$e = -\frac{d}{dt}\int_S \overline{B}\cdot\overline{ds} \qquad (2)$$

where $\overline{s}$ is a unit vector normal to the surface S, and S is the surface bounded by the loop. The induced voltage is proportional to normal component of flux density and to area of the loop.

The flux, ϕ, the source of the pickup, is produced by current flowing in wires or by imperfectly shielded inductive devices, such as transformers and motors. The magnetic field produced by a current I flowing in a closed loop is proportional to the current and to the area of the loop. Thus, inductive pickup depends on the current in the source of pickup and its loop area, the area of the circuit in which pickup occurs, and the spacing of the two loops. The pickup voltage is independent of circuit impedance. Low impedance circuits are, therefore, just as sensitive to inductive pickup as high impedance circuits.

Three steps can be taken to reduce inductive pickup to tolerable levels: shielding, wider spacing, and reducing loop areas to zero.

Shielding against magnetic fields at the power frequencies requires the use of shields constructed of high permeability magnetic materials. Eddy-current screening is not effective above the audio frequency range. Thus to shield a pair of wires from an external magnetic field, run them inside a conduit made of Mumetal or similar materials. Although this is impractical, this method is sometimes used to shield transformers and other inductive devices.

The spacing between the sources of pickup and the sensitive circuits can be increased to only a limited extent. For example, filament and grid leads to the same tube must necessarily be fairly close together. Where possible, coupling can be reduced by running such wires at right angles to each other. Similarly, transformers close to each other should be mounted so that their cores are at right angles.

Loop areas can be reduced to zero or to near zero by running the two wires that make up the two sides of a circuit coaxially, closely parallel, or twisted. Coaxial wire is best, but twisted wire is cheaper and usually adequate. It is possible to estimate the amount of inductive pickup from Equation (2); however, since the remedy—twisting—costs practically nothing, the calculations are unnecessary and are seldom carried out.

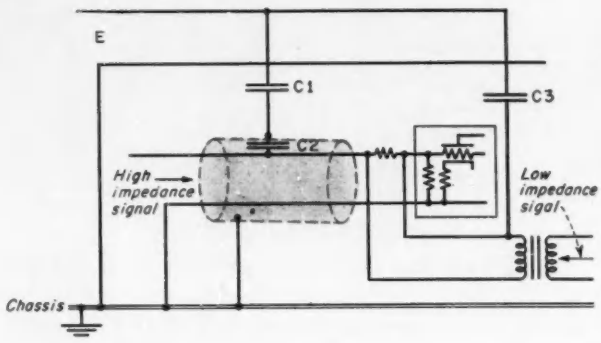
It is important to twist the right leads. The criterion is that the loop area becomes zero or that the algebraic sum of the currents in the twisted set of leads equals zero. Most inductive pickup arises from a failure to observe this rule, or a failure to recognize a loop area. The most common form of mistake is the ground loop. This results from too many ground connections.

A simple ground loop is shown in Figure 5. The circuit is connected to the chassis in two places, at the generator and at the grid. The loop area *abcda* is correctly reduced to zero by twisting. However, there still exists a loop *abefa*. Flux ϕ linking with this loop induces a voltage between grid and cathode of magnitude:

$$E_C = \left(\frac{R_{de}}{R_{dfe} + R_{de}}\right)\frac{d\varphi}{dt} \qquad (3)$$

The pickup voltage depends on the flux variation and on the resistance division (or current division) between the ground wire and chassis. The ground loop can be broken by removing either of the chassis connections, thus preventing pickup.

Ground loops can arise from the interconnection of two or more circuits. In Figure 6 a voltage source feeds two amplifiers in parallel. The *B-minus* wire of the power supply is connected to the low side of each signal line, at points *d* and *f*. This forms a loop *cdgfc*, with consequent pickup at the grids of both amplifiers. The loop can be broken by removing one of the *B-minus* leads, say lead *fg*. The plate



CARE must be taken to shield the complete line. In this diagram only the high impedance signal line is shielded. Thus mutual capacitance C3 may cause pick-up at the grid. Fig. 8

driven from two signals in series, one of high impedance and the other of low impedance. If only the high impedance signal line is shielded, there will be pickup at the grid because of capacitance C3. The complete circuit must be shielded.

When a shielded circuit terminates in a transformer, the transformer winding must also be shielded, Figure 9. In these circuits, the transformer stepdown is so large that the primary wiring needs no shield. The transformer interwinding voltage E_c is induced in the signal line. The coupling impedance $1/2\pi fC$ (where f is the line frequency) is normally much larger than the signal line impedance C. The approximate value of the pickup voltage is

$$E_c = j2\pi fECZ \qquad (4)$$

Thus the capacitive pickup depends on source voltage, frequency, mutual capacitance, and circuit impedance. This pickup is most important in high impedance circuits. When the circuit impedance is resistive, the pickup voltage is in time quadrature with the source of the pickup.

Voltage, frequency, and signal line impedance are known. Mutual capacitance can be estimated. It is then possible to estimate the amount of pickup that is to be expected and to decide in advance whether remedial action is required.

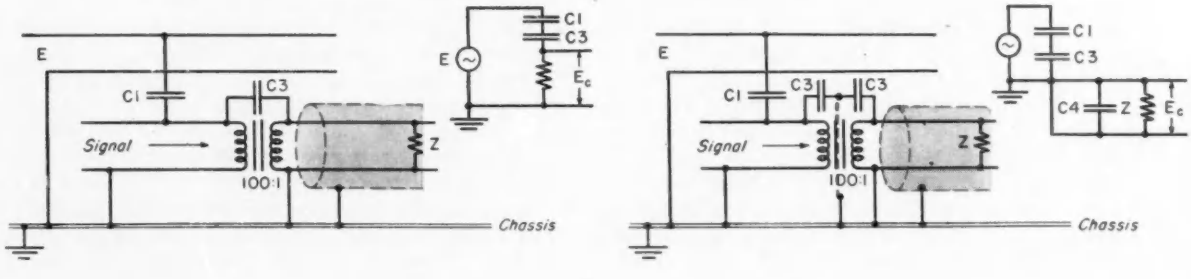
To prevent capacitive pickup, the mutual capacitance must be reduced or made ineffective. Wider spacing can accomplish reduction, but equipment size is a limitation. The remaining mutual capacitance can be made ineffective by shielding the wires with a thin metallic foil or braid, shielding either the source of the pickup or the sensitive circuit. The right side of Figure 7 shows the signal line shielded. Since the capacitive coupling between the two circuits is effectively broken, no capacitive current flows and the pickup is zero. If the shield is not grounded, it is completely ineffective.

The most serious drawback of shielding, aside from its cost, weight, and handling expense, is that it increases the wiring capacitance and may throw this capacitance in parallel with the load. Thus in the right side of Fig. 7, C2 is in parallel with C. In high impedance signal circuits this can cause a significant change in voltage and phase. In addition, the shield capacitance can change with temperature and age. Because capacitance across power circuits is generally not so harmful, it may be preferable to shield the source of pickup.

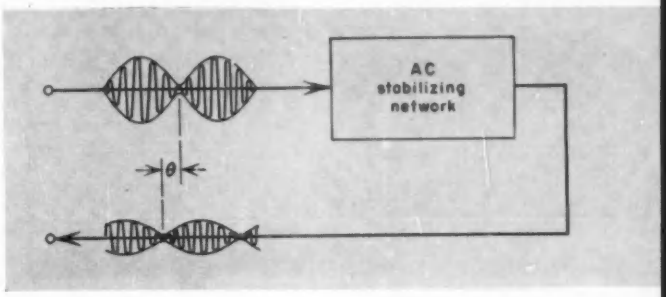
Occasionally shield capacitance is neutralized by special techniques; for example, by double shielding or by driving the shield from the signal source itself through a cathode follower amplifier. These techniques usually require additional equipment and are therefore not generally economical. In most instances the designer faces the fact that a simple shield around the signal circuit itself is the only feasible remedy. Shielding must then be held to the barest minimum, and the signal circuits must be designed to tolerate the shield capacitance and the expected shield capacitance changes.

In shielding a line, it is necessary to shield the complete line including everything that is resistively coupled to it. Figure 8 shows an amplifier that is capacitance will, however, cause pickup in the secondary. In Figure 9 at right, the entire transformer is shielded, and in turn the shield is grounded. This prevents pickup through the interwinding capacitance.

DIAGRAM at left shows a transformer with only the secondary wiring shielded. Using this method, the transformer interwinding capacitance, C3, can cause pickup. Proper technique is shown at right, with transformer windings shielded and the shield grounded. Fig 9



What They Do: When the amplification in an ac feedback system exceeds a critical value, the system breaks into ruinous oscillation. The solution is to install a circuit, called an ac stabilizing network, that predicts probable system error. It squelches or boosts amplifier output in time to forestall oscillation. Result: stability. Frequency response is the key to analysis of the network. As in this drawing,



the modulating signal is shifted ahead and attenuated.

AC Stabilizing Networks

ALFRED D. GRONNER, American Machine & Foundry Co.

How to Choose Them:

Practice follows these three simple steps:

1. Consider the modulation as a dc signal.
2. Go through the design of the control system to determine the necessary frequency response of the stabilizing network to the modulating signal.
3. Then use the selector table at the end of this article to figure the values of circuit parameters.

Theory: The action of direct-current prediction networks is relatively easy to analyze and visualize. Moreover, the design of such networks is well covered in standard servomechanism texts, together with convenient charts and formulas. The principles are briefly reviewed here as a logical approach to the design of the equivalent alternating-current networks. The circuit diagram, transfer function and frequency response of a typical dc rate-sensitive network are given in Figure 2. The output voltage is a rough prediction of the input voltage at a time τ seconds in the future. The term $\frac{1}{(1+\alpha rp)}$ indicates a delay in presenting the prediction. Apparently, the smaller α is, the smaller the delay. But the transfer function also shows that a decrease in α reduces the magnitude of the input signal. A compromise is indicated. α is commonly set equal to $\frac{1}{10}$. Prediction networks have additional properties, such as their tendency to emphasize higher harmonics, but these are not considered here.

In a block diagram, ac and dc servomechanisms appear to be identical.

The instantaneous amplitude of the dc signal is directly proportional to the quantity measured. In ac systems, however, the signals are modulated carrier waves whose peak values correspond to the quantity measured. The carrier envelope must be operated on by the rate-sensitive network to develop a prediction. The networks described do this.

Equation 2 represents the signal applied to an ac network:

$$e_i = E\,(\cos\omega_m)\,(\cos\omega_c t) \tag{2}$$

where E = maximum amplitude of modulating voltage,
ω_m = modulating frequency,
ω_c = carrier frequency.

Equation 2 expands to:

$$e_i = \frac{E}{2}\left[\cos(\omega_c+\omega_m)\,t + \cos(\omega_c-\omega_m)t\right] \tag{3}$$

The network's transfer function to the carrier is G_c; the transfer function to the modulating signal is G_m. Applying the ac signal to the network, the output voltage becomes, in complex notation:

$$e_o = \frac{E}{2}R_e\left\{G_c\left[j(\omega_c+\omega_m)\right]e\,j(\omega_c+\omega_m)t + G_c\left[j(\omega_c-\omega_m)\right]e\,j(\omega_c-\omega_m)t\right\}. \tag{4}$$

In properly adjusted networks,

$G_c[j(\omega_c+\omega_m)]$ is very nearly equal to its conjugate, $G_c[j(\omega_c-\omega_m)]$.

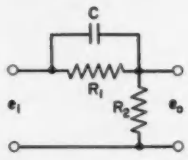
Therefore we represent:

$G_c[j(\omega_c+\omega_m)]$ by the vector $Ae^{j\theta}$
and $G_c[j(\omega_c-\omega_m)]$ by the vector $Ae^{-j\theta}$

Then equation 4 becomes:

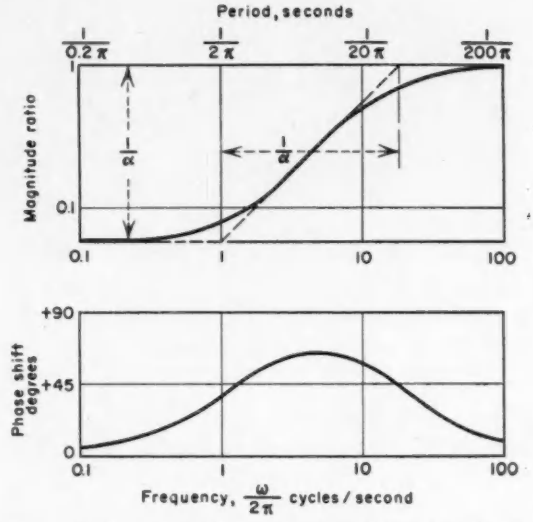
$$e_o = \frac{E}{2}R_e\left\{Ae^{j\theta}\cdot e^{j(\omega_c+\omega_m)t} + Ae^{-j\theta}\cdot e^{j(\omega_c-\omega_m)t}\right\}$$

$$= \frac{E}{2}R_e\left\{Ae^{j[(\omega_c+\omega_m)t+\theta]} + Ae^{j[\omega_c-\omega_m)t-\theta}\right.$$



$$\frac{e_o}{e_i} = \alpha \frac{(1+\tau P)}{(1+\alpha\tau P)} \qquad \text{Eq. 1}$$

where $\tau = R_1 C$ and $\alpha = \frac{R_2}{R_1+R_2}$



The prediction network attenuates low frequency signals, passes high frequency signals unattenuated. Over a finite range of frequencies, the output leads the input. Maximum phase lead is a function of α, increasing as α decreases.

Returning to the trigonometric notation:

$$e_o = \frac{EA}{2}\left\{\cos\left[(\omega_c+\omega_m)t+\theta\right] + \cos\left[(\omega_c-\omega_m)t-\theta\right]\right.$$

which reduces to:

$$e_o = EA\cos\omega_c t \cdot \cos(\omega_m t+\theta) \qquad (5)$$

Since the input signal to the network is E $(\cos \omega_m t)$ $(\cos \omega_c t)$, the network has effectively shifted the phase of the modulation by the angle θ and has attenuated its amplitude by A. The network operated *only on the modulation.*
Then

$$G_m(j\omega_m) = G_c\left[j(\omega_s+\omega_m)\right] = Ae^{j\theta}$$

In Figure 3 the frequency response of the network is shifted from its center about the carrier frequency to a center about zero frequency. The result represents the frequency response to the modulation. Note the similarity between the frequency response characteristics in Figure 2 and in Figure 3.

Application to Specific Networks

An approximation is devised to obtain the transfer function of an ac lead network equivalent to its dc counterpart:

$$j\omega_m = j(\omega-\omega_c) \cong j\frac{(\omega-\omega_c)(\omega+\omega_c)}{2\omega}$$

$$\cong \frac{\omega_c^2+(j\omega)^2}{2j\omega} \qquad (6)$$

The design formulas of the resonant lead network shown in Figure 5 are derived as an example. The *LC* circuit is tuned to the carrier frequency, ω_c.

Therefore $\omega_c^2 = \frac{1}{LC}$

The network transfer function, $G_c(j\omega)$, is calculated:

$$\frac{e_o}{e_i} = \frac{j\omega L + \frac{1}{j\omega C} + R_2}{j\omega L + \frac{1}{j\omega C} + R_1 + R_2}$$

which factors to

$$\frac{e_o}{e_i} = \frac{\frac{L\left[\omega_c^2+(j\omega)^2\right]}{j\omega} + R_2}{\frac{L\left[\omega_c^2+(j\omega)^2\right]}{j\omega} + R_1 + R_2}$$

Transforming with equation 6 we get the transfer function $G_m(j\omega_m)$ for the modulation:

$$G_m(j\omega_m) = \frac{2j\omega_m L + R_2}{2j\omega_m L + R_1 + R_2}$$

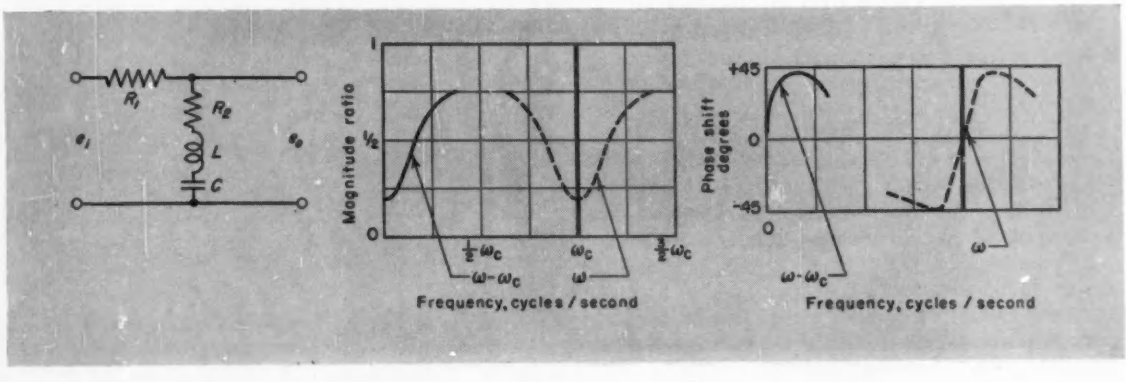
Defining $\tau = \frac{2L}{R_2}$ and $= \alpha = \frac{R_2}{R_1+R_2}$,

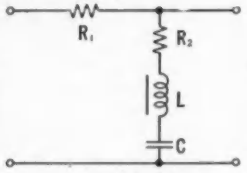
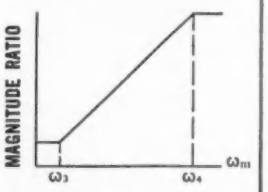
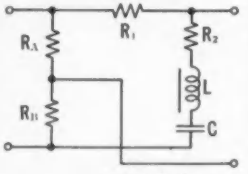
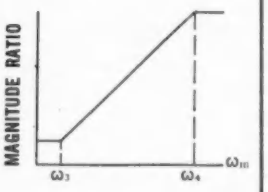
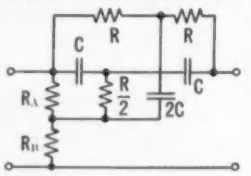
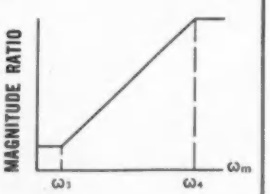
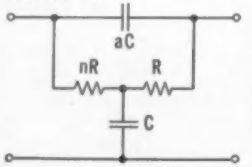
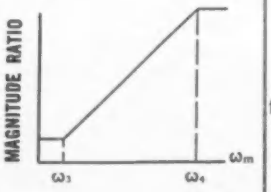
we obtain

$$G_m(j\omega_m) = \alpha\frac{(1+\tau j\omega_m)}{(1+\alpha\tau j\omega_m)}$$

The design formulas of other ac lead networks in Table 1 are derived by a similar transformation.

Frequency response of a resonant ac stabilizing network. Fig. 3.



NETWORK	FREQUENCY RESPONSE OF EQUIVALENT DC NETWORK	FORMULAS WHEN CONSTANTS ARE KNOWN	FORMULAS WHEN BREAK FREQUENCIES ARE KNOWN	PRACTICAL CONSIDERATIONS
RESONANT  $G_m = \alpha \frac{1+\tau j\omega_m}{1+\alpha\tau j\omega_m}$	 	$C = \frac{1}{\omega_c^2 L}$ $\tau = \frac{1}{\omega_c} = \frac{2L}{R_2}$ $\alpha = \frac{R_2}{R_1+R_2}$	$L = \frac{R_2}{2\omega_3}$ $C = \frac{2\omega_3}{R_2\omega_c^2}$ $R_1 = R_2\frac{\omega_4-\omega_3}{\omega_3}$ R_2 arbitrary	Choke and condenser have to be exactly adjusted to resonance. Temperature coefficient of choke presents problems. Q of choke limits ω_3. Choke has to include air gap to avoid harmonic generation. ω_3 and ω_4 can be adjusted independently.
MODIFIED RESONANT  $G_m = (1-n)\alpha \frac{1+\tau j\omega_m}{1+\alpha\tau j\omega_m}$	 	$C = \frac{1}{\omega_c^2 L}, n = \frac{R_B}{R_A+R_B}$ $Q = \frac{\omega_c L}{R_2}$ $\omega_3 = \frac{1}{\tau} = \frac{\omega_c^2}{2}\left(\frac{1}{\omega_c Q} - \frac{n}{1-n}R_1 C\right)$ $\omega_4 = \frac{1}{\alpha\tau} = \frac{\omega_c^2}{2}\left(R_1 C + \frac{1}{\omega_c Q}\right)$	$n = \frac{R_B}{R_A+R_B}$ $C = \frac{2\omega_4}{R_1\omega_c^2} - \frac{1}{R_1\omega_c Q}$ $L = \frac{R_1 Q}{2\omega_4 Q - \omega_c}$ $n = \frac{\omega_c - 2\omega_3 Q}{2Q(\omega_4-\omega_3)}$ $Q = \frac{\omega_c L}{R_2}$; R_1 arbitrary	Features are similar to the simple resonant stabilizing network except that there is no lower limit to ω_3. ω_3 is conveniently adjusted experimentally by replacing R_A and R_B with a potentiometer. Lower limit to ω_3/ω_4 is determined by noise sensitivity. Applies especially to third harmonics generated by iron cored chokes.
SYMMETRICAL PARALLEL "T"  $G_m = \alpha \frac{1+\tau j\omega_m}{1+\alpha\tau j\omega_m}$	 	$m = \frac{R_B}{R_A+R_B}$ $\omega_c = \frac{1}{RC}$ $\omega_3 = \frac{1}{\tau} = 2m\omega_c$ $\omega_4 = 2\omega_c$	$m = \frac{R_B}{R_A+R_B}$ $RC = \frac{1}{\omega_c}$ $m = \frac{\omega_3}{2\omega_c}$	ω_3 is conveniently adjusted by replacing R_A and R_B with a potentiometer. Very serious limitation is that maximum ω_4 is limited to twice the carrier frequency. To be useful in the servo band, very large attenuations are therefore required. Consequently the signal-to-noise ratio is poor. High quality components are required to avoid detuning from carrier frequency with ageing and temperature.
BRIDGED "T"  $G_m = \alpha \frac{1+\tau j\omega_m}{1+\alpha\tau j\omega_m}$	 	$\omega_3 = \frac{1}{RC}\frac{n+1}{2n}, \omega_4 = \frac{n+a+an}{2anRC}$ $\omega_c = \frac{1}{RC}\sqrt{\frac{1}{an}}$ for n = 1: $\omega_3 = \frac{1}{RC}$ $\omega_4 = \left(1+\frac{1}{2a}\right)\frac{1}{RC}$ $\omega_c = \frac{1}{RC}\sqrt{\frac{1}{a}}$	$C = \frac{1+n}{2n}\frac{1}{\omega_3 R}$ $a = \frac{2\omega_3}{(n+1)\omega_c^2}$ $\omega_4 = \omega_3\left(1+\frac{n\omega_c^2}{2\omega_3^2}\right)$ for n = 1: $C = \frac{1}{\omega_3 R}$, $a = \frac{\omega_3^2}{\omega_c^2}$ $\omega_4 = \omega_3\left(1+\frac{\omega_c^2}{2\omega_3^2}\right)$	Similar to symmetrical bridged "T" network. Under most conditions this network results in an ω_4 higher than that of the parallel "T" network. The advantage of this network is the small number of components used.

ROUND-UP: 12 WAYS OF

Generating Control

For the first time these circuits have been classified by function so that the control system designer can determine at a glance the basic circuit, principle of operation, performance equation, and frequency response.

Background:

A flexible set of control tools that will handle all conditions of regulation and stability must be able to generate three types of control functions (or combinations of them). The functions are: *Proportional-position*, where the output signal is proportional to the actuating signal; *Reset* (or *integral*), where the output signal is proportional to the time integral of the actuating signal; and *Rate* (or *derivative*) where the output signal is proportional to the rate of change of the actuating signal. The combinations of these functions most commonly used are

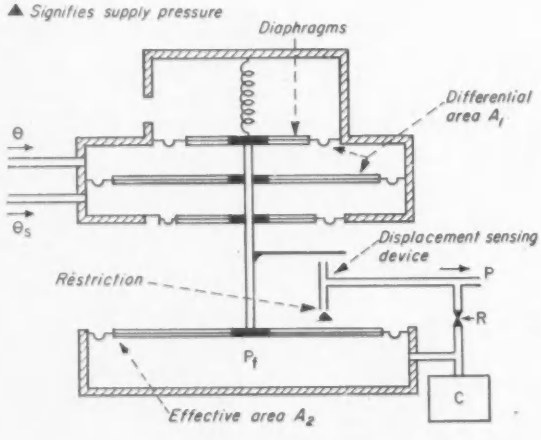
- Proportional-position
- Proportional plus reset
- Proportional plus rate
- Proportional plus reset plus rate

In pneumatic control systems these control actions are generated by feeding back the output signal or modifying the actuating signal. Feedback may be lagged or direct, negative or positive, depending on the specific circuit and on the desired function.

Typical Example

Figure 1 shows a typical force balance controller with negative feedback of the output pressure.

When resistance is used in the feedback circuit (R unequal to zero), the feedback pressure lags behind the output pressure after a sudden change in θ This causes P to increase an amount proportional to the change in θ plus an amount proportional to the rate of change of θ. In response to a sinusoidal signal the output pressure P leads the input signal θ by a definite phase angle depending on the value of the



Typical pneumatic control circuit using delayed negative feedback to generate rate action. Fig. 1.

θ = controlled variable P_f = feedback pressure
θ_s = reference input P = output pressure
P_s = equilibrium value of P and P_f when $\theta = \theta_s$
A_1 = differential area acted on by θ and θ
A_2 = area of feedback diaphragm
R = variable resistance
C = capacitance associated with P_f

An increase in θ from the equilibrium value will cause the diaphragm assembly to move down. This throttles the flow from the displacement-sensing device, increasing the output pressure P and feedback pressure P_f. The force on area A_2 balances the forces on differential area A_1, so that the new value of P is proportional to the increase in θ. Thus the static equilibrium equation can be written,

$$(\theta - \theta_s)A_1 - (P_f - P_s)A_2 = \epsilon A_2(P - P_s) \qquad (1)$$

where ϵ is a small number. If P is zero, $P_f = P$, and equation (1) reduces to

$$\frac{P - P_s}{\theta - \theta_s} = \frac{A_1}{A_2}\left[\frac{1}{1+\epsilon}\right] = \frac{A_1}{A_2}, \qquad (2)$$

the equation for a proportional-position controller.

W. I. CALDWELL, Taylor Instrument Companies

Functions Pneumatically

resistance, R, and capacitance, C. For practical purposes these pressures obey the relationship

$$(P - P_s) = P_f - P_s + T\frac{d}{dt}(P_f - P_s) \qquad (3)$$

where $T = RC$, a constant with time dimensions.

Substituting the expression for $(P_f - P_o)$ from Equation (3) into Equation (1),

$$(1 + \epsilon)(P - P_s) + \epsilon T\frac{d}{dt}(P - P_s) =$$

$$\frac{A_1}{A_2}(\theta - \theta_s) + T\frac{d}{dt}(\theta - \theta_s) \qquad (4)$$

In operational notation,

$$\frac{P - P_s}{\theta - \theta_s} = \frac{A_1}{A_2}\frac{(1 + Tp)}{(i + \epsilon Tp)}$$

By comparing this with Equation (8) it can be seen that

T = rate time = RC,

$a = 1/\epsilon$, a large number when ϵ is small

This demonstrates how rate action is obtained in a pneumatic circuit by delayed negative feedback. Material on following pages shows a variety of pneumatic circuits that use internal feedback to generate this and other combinations of control functions.

General Performance

Here are the general performance equations and frequency response plots for pneumatic circuits that generate the four basic combinations of control functions. High frequency terms are left out of these equations so that they describe performance somewhat below the cut-off frequency, f_c. In the frequency response plots M is the ratio of the amplitude of the output signal to the amplitude of a sinusoidal actuating signal.

Figure 2 is a composite diagram whose foundation is the frequency response plot of a proportional-position controller. Addition of reset action to the controller adds the portions shaded in red. The gray-shaded portions are the result of including rate action in the controller.

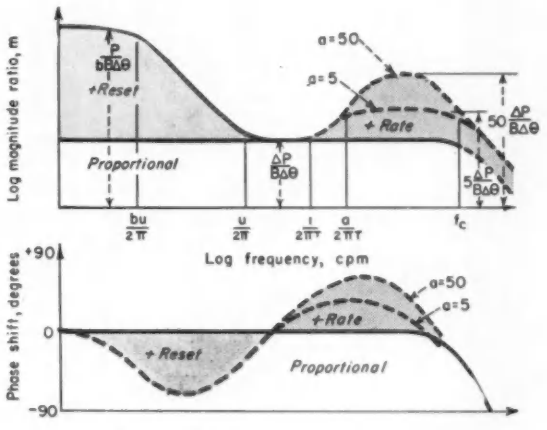
The generalized equations follow:

Proportional-position

$$\frac{P - P_s}{\theta - \theta_s} = \frac{\Delta P}{B\Delta\theta} \qquad (5)$$

where B = proportional band

θ = controlled variable



θ_s = reference input

$\theta - \theta_s$ = actuating signal

$\Delta\theta$ = full-scale range of controlled variable

P_s = output pressure when actuating signal is zero

P = output pressure

ΔP = full working range of output pressures (12 psi for example).

Proportional Plus Reset

$$\frac{P - P_s}{\theta - \theta_s} = \frac{\Delta P}{B\Delta\theta}\left[\frac{1 + U/p}{1 + bU/p}\right] \qquad (6)$$

where U = reset rate, the number of times the proportional effect is repeated per minute.

b = small number (Its value may or may not change with the value of B).

p = Heaviside operator = $\frac{d}{dt}$

Proportional Plus Rate

$$\frac{P - P_s}{\theta - \theta_s} = \frac{\Delta P}{B\Delta\theta}\left[\frac{1 + Tp}{1 + Tp/a}\right] \qquad (8)$$

where T = rate time, minutes or seconds

a = large constant depending on controller design

Proportional Plus Reset Plus Rate

$$\frac{P - P_s}{\theta - \theta_s} = \frac{\Delta P}{B\Delta\theta}\left[\frac{U/p + 1 + Tp}{bU/p + 1 + Tp/a}\right] \qquad (9)$$

References

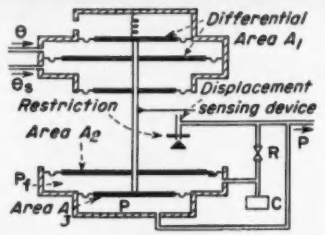
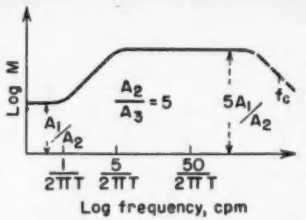
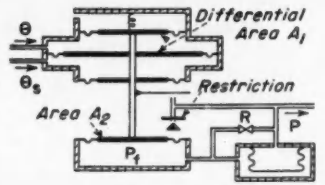
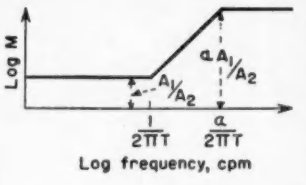
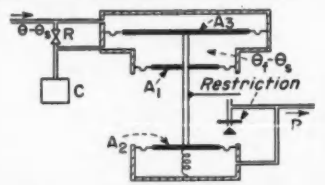
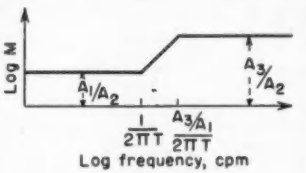
Aikman, A. R. and Rutherford, C. I., "The Characteristics of Air-Operated Controllers."

J. M. L. Janssen, "Analysis of Pneumatic Controllers"; both published in *Automatic & Manual Control*. Butterworths Scientific Publications, 1952.

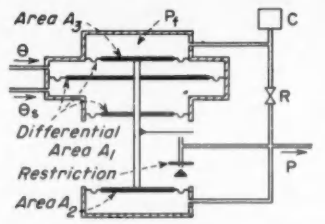
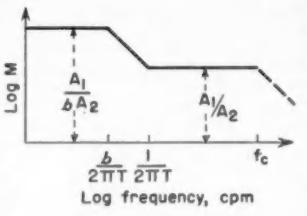
A. J. Young, "Control of Chemical Processes"; Aug., 1953; March, 1954; May, 1954 issues of *Instruments & Automation*.

Details of the 12 Ways

Circuits for Generating—PROPORTIONAL PLUS RATE

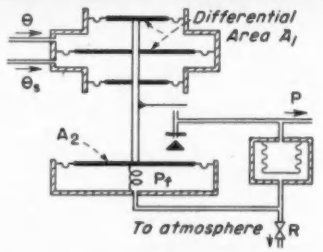
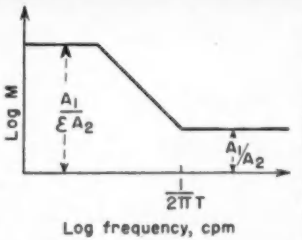
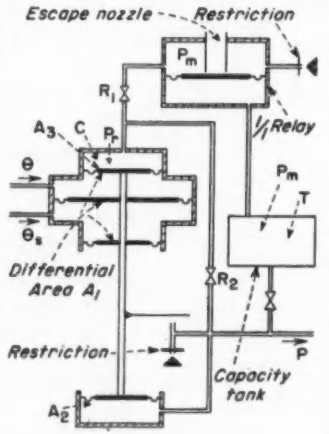
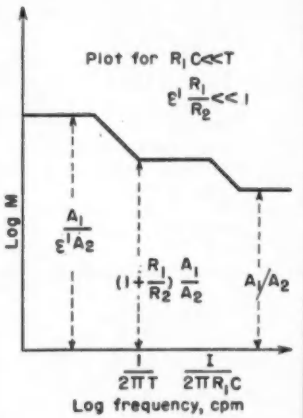
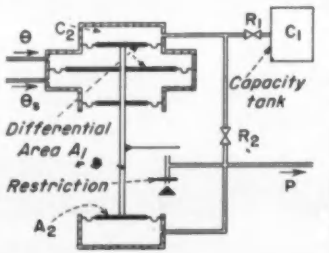
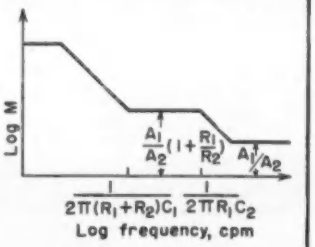
Description	Basic Circuit	Operational Equation	Magnitude Ratio	Remarks
Circuit of Fig. 1 modified by the addition of direct (not delayed) feedback.		$\frac{P-P_o}{\theta-\theta_s}=\frac{A_1}{A_2}\left[\frac{1+Tp}{1+(\epsilon+A_3/A_2)Tp}\right]$ where $\frac{1}{\epsilon+A_3/A_2}=\frac{A_2}{A_3}=a$ if $\epsilon << A_2/A_3$		At low frequencies P_f follows P and M is equal to A_1/A_2. At high frequencies little air bleeds through R, and M equals $aA_1/A_2=(A_1/A_3)$. The controller response depends on the fixed design constant a. Maximum lead time of ramp response, maximum phase lead, and maximum increase in ratio of amplitude varys with a. When a equals unity, response corresponds to that of a proportional-position circuit.
Control action similar to that of previous circuit.		$\frac{P-P_o}{\theta-\theta_s}=\frac{A_1}{A_2}\left[\frac{1+Tp}{1+Tp/a}\right]$ if $\epsilon<<1$ and $\epsilon<<\frac{1}{a}$ where 1/a is the change in P_f for a unit change in P when R is completely closed		At low frequencies P_f follows P, and M equals A_1/A_2. At high frequencies little air bleeds through R. However, elongation of bellows with increase in P causes a corresponding but larger change in P_f. This provides direct feedback which limits the value of M to aA_1/A_2.
Proportional-plus-rate response obtained by lagging part of the input instead of the output.		$\frac{P-P_o}{\theta-\theta_s}=\frac{A_1}{A_2}\left[\frac{1+(A_3/A_2)T_1p}{1+T_1p}\right]$ where $T=\frac{A_2}{A_1}T_1 \quad a=A_3A_1$ if $\epsilon<<1$		At low frequences θ_f essentially follows θ and the value of M is A_1/A_2. At high frequencies little air bleeds through R, θ_f remains essentially constant and M equals $aA_1/A_2=(A_3/A_2)$. This circuit has been used in a force-balance mechanism.

Circuits for Generating—PROPORTIONAL PLUS RESET

Circuit generates proportional-plus-reset action by use of negative feedback plus lagged positive feedback.		$\frac{P-P_o}{\theta-\theta_s}=\frac{A_1}{A_2}\left[\frac{1+1/Tp}{1+(1+\epsilon-A_3/A_2)/Tp}\right]$ $U=1/T$ $b=1+\epsilon-A_3/A_2$ (By adjustment of A_3/A_2, b can be made small and b/Tp term neglected)		At low frequencies P_f about equals P, and the negative feedback essentially cancels the positive feedback. Consequently small changes in $\theta-\theta_s$ cause large changes in P. At high frequencies, P_f is essentially constant so that M is equal to A_1/A_2. Feedback circuit is used in motion-balance controllers where proportional band is adjusted by linkage.

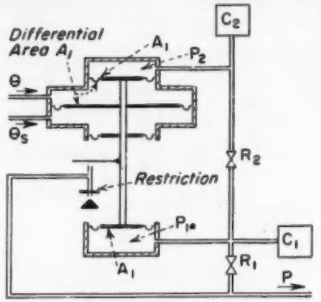
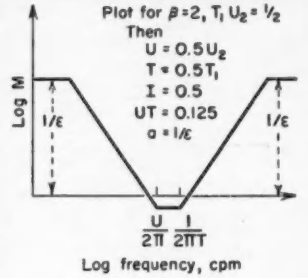
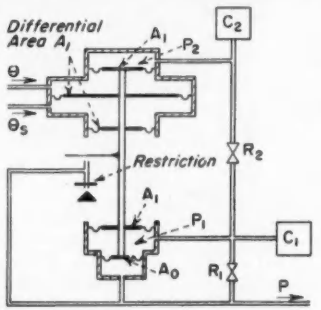
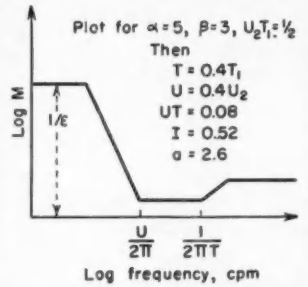
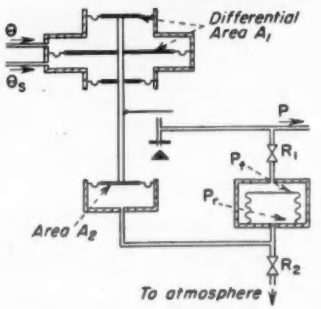
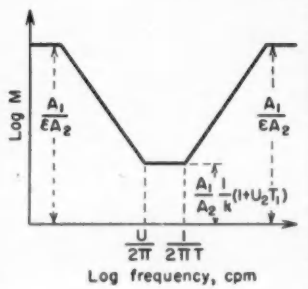
▲ indicates supply pressure.

Circuits for Generating—PROPORTIONAL PLUS RESET

Description	Basic Circuit	Operational Equation	Magnitude Ratio	Remarks
Single feedback pressure used to obtain proportional-plus-reset action.		$\frac{P-P_o}{\theta-\theta_s}=\frac{A_1}{A_2k}\left[\frac{1+1/Tp}{1+\varepsilon/kTp}\right]$, if $\varepsilon<<k$ $U=1/T$ $b=\varepsilon/k$ k = change in P_f for a unit change in P when R is closed		At low frequencies P_f is almost equal to atmospheric pressure, there is no feedback, and the value of M is high. At high frequencies the action of P on the bellows causes a corresponding change in P_f. The resultant feedback reduces the amplitude of P. Circuit is used in motion-balance controllers where proportional band is adjusted by linkage.
Modification of the first proportional - plus - reset circuit using a pressure divider for adjustment of the proportional bandwidth.		$\frac{P-P_o}{\theta-\theta_s}=\frac{\frac{A_1}{A_2}\left(1+\frac{R_1}{R_2}\right)\left(\frac{1}{Tp}+1\right)\left(1+\frac{R_1Cp}{1+R_1/R_2}\right)}{\left(1+\frac{R_1}{R_2}\right)\frac{\varepsilon'}{Tp}+\left(\frac{R_1C}{T}+1+\varepsilon'\frac{R_1}{R_2}\right)+R_1Cp}$ where $\varepsilon'=1+\varepsilon-A_3/A_2$ When operating frequency is between $\frac{1}{2\pi T}$ and $\frac{1}{2\pi R_1C}$ then $U=1/T$ $B=\frac{A_2}{A_1}\frac{R_2}{R_1+R_2}\frac{\Delta P}{\Delta\theta}$		The pressure divider R_1R_2 proportions the positive feedback pressure between the output pressure P and the lagged pressure P_m. The amount of cancellation of the negative feedback by the action of P on the negative feedback pressure and the proportional response of the controller depends on the ratio R_1/R_2. The one-to-one relay applies the pressure P_m in the capacity tank to the pressure divider circuit without permitting flow between them. This makes the reset rate, 1/T, independent of the values of R_1 and R_2. By modifying the circuit so that a reducing valve supplies P_m to the pressure divider, the circuit has proportional-position action with the bandwidth adjustable by changing the ratio R_1/R_2. These circuits are used in force-balance stacked-diaphragm controllers.
Modification of first proportional-plus-reset circuit which uses a pressure divider for adjustment of the proportional bandwidth and of the reset rate.		$\frac{P-P_o}{\theta-\theta_s}=\frac{A_1}{A_2}\left(1+\frac{R_1}{R_2}\right)\left[\frac{\frac{1}{(R_1+R_2)C_1p}+1+\frac{R_1R_2C_2p}{(R_1+R_2)}}{\frac{\varepsilon}{R_2C_1p}+1+R_1C_2p}\right]$ if $C_2<<C_1$ and $\varepsilon<<R_2/R_1$ When the operating frequency is between $\frac{1}{2\pi(R_1+R_2)C_1}$ and $\frac{1}{2\pi R_1C_2}$ then $U=\frac{1}{(R_1+R_2)C_1}$ and $B=\frac{\Delta P}{\Delta\theta}\frac{A_2}{A_1}\frac{R_2}{R_1+R_2}$		The pressure divider circuit controls the proportional bandwidth and the reset rate. When the value of either resistance is changed, the values of both the bandwidth and reset rate are changed. This circuit is used in a stacked-diaphragm controller.

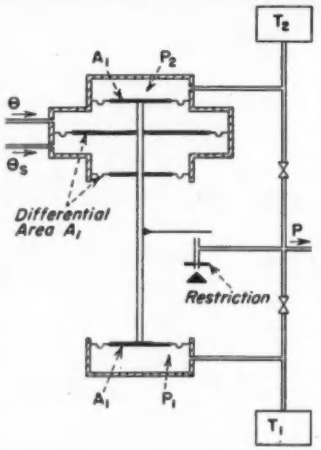
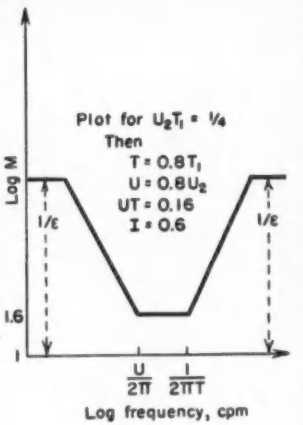
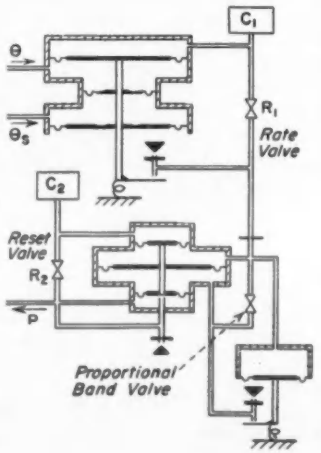
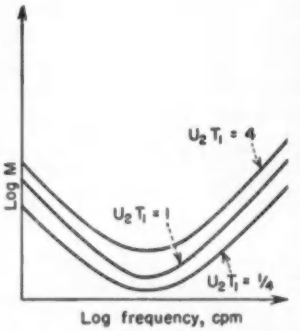
▲ indicates supply pressure.

Circuits for Generating—PROPORTIONAL PLUS RESET PLUS RATE

Description	Basic Circuit	Operational Equation	Magnitude Ratio	Remarks
Feedback circuit with resistance in series.		$\frac{P-P_o}{\theta-\theta_s}=(1+\beta T_1U_2)\left[\frac{\frac{U_2/p}{1+\beta T_1U_2}+1+\frac{T_1p}{1+\beta T_1U_2}}{\epsilon U_2/p+1+\epsilon T_1p}\right]$ where $\epsilon\beta T_1U_2<<1$ $T_1=R_1C_1$ $U_2=1/R_2C_2$ $\beta=1+C_2/C_1$		This circuit is used in motion-balance controllers where proportional band is adjusted by linkage.
Feedback circuit with resistance in series plus direct negative feedback.		$\frac{P-P_o}{\theta-\theta_s}=\frac{1+U_2T_1\beta}{1+U_2T_1\beta/a}\left[\frac{\frac{U_2/p}{1+U_2T_1}+1+\frac{T_1p}{1+U_2T_1\beta}}{\frac{\epsilon U_2/p}{1+U_2T_1\beta/a}+1+\frac{(T_1/a)p}{1+U_2T_1\beta/a}}\right]$ where $a=A_1A_0$ $\quad T_1=R_1C_1$ $\beta=1+C_2/C_1$ $\quad U_2=1/R_2C_2$ $\epsilon<<1$ $\quad \epsilon<<A_0A_1$ Then $T=T_1/(1+U_2T_1)$ $U=U_2/(1+U_2T_1)$		Used in motion-balance controllers where proportional band is adjusted by linkage.
Three-response circuit having a single feedback diaphragm.		$\frac{P-P_o}{\theta-\theta_s}=\frac{A_1}{A_2k}[1+U_2T_1]\left[\frac{\frac{U_2/p}{1+U_2T_1}+1+\frac{T_1p}{U_2T_1}}{U_2/kp+1+(T_1/k)p}\right]$ assuming $k<<1$ and $\epsilon<<k/(1+U_2T_1)$ k is the ratio of change of P_r to P_f when $R_2=\infty$ $U=U_2/(1+U_2T_1)$ $T=T_1/(1+U_2T_1)$ $I=k/(1+U_2T_1)$		This circuit is used in a motion-balance controller where the proportional band is adjusted by linkage.

▲ indicates supply pressure.

Circuits for Generating—PROPORTIONAL PLUS RESET PLUS RATE

Description	Basic Circuit	Operational Equation	Magnitude Ratio	Remarks
Control action obtained by retarding both positive and negative feedback. For simplified analysis all areas and differential areas are assumed equal.		$\frac{P-P_o}{\theta-\theta_s}=\frac{1+U_2T_1}{1-U_2T_1}\left[\frac{\frac{U_2/p}{1+U_2T_1}+1+\frac{T_1p}{1+U_2T_1}}{\frac{\varepsilon U_2/p}{1-U_2T_1}+1+\frac{\varepsilon T_1p}{1-U_2T_1}}\right]$ where $\varepsilon<<1$ $U_2=1/T_2$ Then T_1=rate time when $U_2=0$ ($T_2=\infty$) U_2=reset rate when $T_1=0$ Using both reset and rate $T=T_1/(1+U_2T_1)$=rate time $U=U_2/(1+U_2T_1)$=reset rate and the proportional band is decreased by $I=\frac{1-U_2T_1}{1+U_2T_1}$ where I=interaction factor		With this circuit the largest practical value of U_2T_1 is about 0.25. Feedback circuit is used in motion-balance controllers where proportional band is adjusted by linkage.
Three stages in series; proportional-plus-rate stage followed by a proportional-amplification stage and a proportional-plus-reset stage. Used to prevent overshoot during startup.		$\frac{P-P_o}{\theta-\theta_s}=S_1(1+U_2T_1)\left[\frac{U_2/p}{1+U_2T_1}+1+\frac{T_1p}{1+U_2T_1}\right]$ where S_1=proportional amplification term dependent on the setting of the valve in the amplification stage $T_1=R_1C_1$ $U_2=\frac{1}{R_2C_2}$ Effective values are: $U=\frac{U_2}{1+U_2T_1}=\frac{1/T_1}{1+1/U_2T_1}$ $T=\frac{T_1}{1+U_2T_1}=\frac{1/U_2}{1+1/U_2T_1}$ $I=1/(1+U_2T_1)$ When U_2T_1 is small, $U\cong U_2$, $T\cong T_1$ When $U_2T_1>>1$, $U\cong\frac{1}{T_1}$, $T\cong\frac{1}{U_2}$		By proper adjustment, input to reset stage can be made to lead controlled variable by sufficient time to bring process under control without overshoot. Response curves are normal for normal load changes. Often a good setting for startup and load change is obtained by making U_2T_1 equal unity. This circuit is used in a force-balance controller.

I = interaction, a term which indicates how much th proportional band of a controller is increased by the interaction of the reset and rate effects.

▲ indicates supply pressure.

What Computers Promise

Exciting new applications, many experimental, inflate the dreams of engineers and laymen alike. But a desperate need has arisen for men who know computers and have the imagination to capitalize on them.

DAVID RUBINFIEN, Armour Research Foundation

GIANT DIGITAL COMPUTERS, handling an increasing share of office work or solving overwhelming technical problems, are often compared with regiments of clerks wielding pencils or battalions of engineers brandishing slide rules. The analog computers, steadily finding new jobs in process control, are likened to human operators with the eyes of Argus and the limbs of a millipede.

Comparisons of this sort are generally misleading. Computers are information processing devices. They perform long series of elementary logical and arithmetical operations on information and condense it to useful forms. As such, computers complement man's deductive processes. Merely equating their speed with human bustle gives computers both less and far more than their due. Mechanical and electronic "brains" cannot compete with the human mind's scope, capacity, flexibility, or adaptability.

A Look Back

The two species of computer—analog and digital—evolved along separate lines, which are now converging. Apart from such isolated examples as Babbage's Difference Engine (1812) and Kelvin's mechanical Differential Analyzer (1876), computer history begins with the punched-card office machines of 60 years ago. They worked digitally; that is, bit-by-bit, as a man does arithmetic.

The scientific manpower shortage of World War II demanded machines that could handle routine but rather complicated calculations. Thus, out of desperate necessity, were born the Bell Labs computers, Harvard's Mark I, the Eniac, and the Edvac. Each of this new breed of increasingly fast digital machines spent much of its early life grinding out ballistics tables for the Armed Forces. They solved humdrum problems at superhuman speed.

Analog computer history is shorter. The first modern machine to achieve unqualified success was Dr. Vannevar Bush's differential analyzer, built at the Massachusetts Institute of Technology more than 20 years ago. Like the early digital machines, Dr. Bush's analyzer was a general-purpose problem solver. But the analog computers that followed during the war developed as components in control systems. Pioneer examples were the computers which helped the M-4 (mechanical) and M-9 (electronic) antiaircraft gun directors track enemy planes.

A Look Around

Today, well-rounded computer centers use analog machines to simulate physical relationships in order to bypass lengthy calculations. Automobile manufacturers, for example, have applied analog computers to such problems as engine crankshaft vibrations, design of valve systems, improved carburetion techniques, power-aided steering, spring and shock absorber systems, and overall road stability.

In the aircraft industry complete airplanes have been set up on elaborate electronic analog machines to simulate the aerodynamic phenomena, the instruments, and the automatic controls. In some instances, experienced pilots "fly" experimental aircraft in the computer laboratory in order to include the human responses which govern flight behavior. The pilot manipulates regular aircraft controls which are linked so that the computer mimics a real plane's responses. With the snap of a switch, the computer operator can subject the "plane" and its pilot to theoretical gusts, air pockets, component failures, and other hazards of flight. Hundreds of systems designs can be tested without ever going to the shop or subjecting humans to real danger.

For designers of automatic control systems, com-

"One can visualize entirely new and different production

AUTHOR RUBINFIEN is Chicago-born, -trained, and -employed. The mathematics he learned at Illinois Tech led him to Armour, where he has been head of the Foundation's computer work since its start in 1949. He now concentrates on computer applications rather than development, and also on operations research. The service rendered by his computer center leads him into many fields, including: weapons evaluation, flight systems, guided missiles, machine tool control, utilities network planning, and automatic packaging machinery.

puters have a special interest. Take, for example, the design of a chemical pilot plant—normally a costly procedure. A highly refined mathematical model is relatively easy to set up in an analog computer, which can swiftly examine the effects on control of such factors as amplitude and phase response, drift, noise, stability, and various nonlinearities.

Recently one of our large progressive midwestern oil companies concluded a series of such computations on a proposed petrochemical plant. The analog computer "built" a large-scale refinery with question marks regarding the speed of response of several dozen automatic control valves and the settings of as many manual valves.

Were the speeds of the various controllers limiting factors? And what were the optimum settings for valves so the plant would meet the process requirements? Many hundreds of variations in operating conditions were simulated. These tests put the automatic valves through all their paces. Needless to say, more than half of these situations produced either catastrophic "explosions" or other less dramatic system failures. The remaining group outlined a set of operating bounds within which the controllers could work effectively. Simultaneously, a wide range of set points had been checked out to meet the many vessels' pressure and temperature requirements and the flow rates prescribed by the chemical engineers.

How does a computer perform as a component in a control system? And what are the properties that suit it to each application?

The control engineer working in the process industries is familiar with pneumatic relays which add, multiply, integrate, and take ratios, averages, and square roots. Such relays are actually computers, whose functions are analogous to the actions and interactions of the process.

But now the engineer is trying to capitalize on the higher precision, immense capacity, and ultimately lower cost of digital computers to regulate industrial processes. Here the computer's task is to scrutinize and integrate perhaps hundreds of variables; for example, the pressures, temperatures, and fluid flows in the piping and interconnected vessels of a petroleum refinery. Instantaneously and untiringly, the computer must comprehend changes in the system, correlate their effects, and without faltering issue the necessary commands for keeping the process under control.

The computer that does this work must be fast; it must have the capacity to consider many variables; it must be flexible enough to handle many situations; and if it is to maintain the process at an optimum level, it must be able to reproduce its decisions with great precision.

The principal justification, then, for using a computer within a control system is its ability to process vast amounts of information sequentially through well-defined relationships with extreme speed and consistency. But this computer does not replace a simple-minded oaf. Rather it substitutes for a man, or staff of men, with tremendous memory capacity and the ability to correlate and organize data into highly complex relationships. These men nowadays read instrument charts, interpret their meaning into over-all process performance, and adjust controls to keep this performance as close as possible to optimum levels. They make countless decisions and rely upon a vast store of information accrued through long experience with the process.

In terms of replacing men, the present-day computer is equal to the task in only a very limited area. In particular, it surpasses men where a mere multiplicity of extremely elementary operations is required. Where the governing relationships in a process are extremely complex, ill defined, or even impossible to define, the computer cannot begin to compete with its human counterpart. In its ability to remember past situations of any complexity and to recall them in order to meet new situations, the computer's speed and memory capacity again fall

A LOOK AHEAD ➡

systems based on computer applications."

very short of that required for adequate control.

As far as flexibility goes, the ability of a computer to extrapolate from the "images" it retains to new situations is again limited by the complexity of the extension to be made. The same quality of sequential operations, even at very high ratio of speed, cannot compare to man's essentially simultaneous processing of streams of sensed information. Although computers might conceivably be designed with a higher degree of such parallel operation, they might well prove immediately uneconomical. At best, one might expect a computer to perform over very limited ranges of variation in complex systems and to be supplemented by human control outside of these ranges. But this same limitation holds true for every control application today—there is the physical stop or limit switch or alarm bell that demands human attention to the process.

Reproducibility—which often means accuracy—is the computer's shining quality in process control and similar applications. Returning to the petroleum refinery and its multiplicity of controls, the human operator cannot be expected to arrive at the optimum settings every time. The same quality which makes man flexible enough to meet a range of emergencies seems to cause him to handle a situation a little differently each time it arises. If he is expert, he sets the controls cleverly and the process operates well. That is the best he can expect to do. The computer, in contrast, handles a given set of conditions in precisely the same way each time it arises. Only a computer, therefore, can convert optimum operating conditions from a goal to a reality.

Digitals Enter Control

There are today numerous "closed-loop" applications where the digital computer is equal to its task and is rapidly being adopted. Many of these again lie in military applications. Digital computers have been designed for fire-control systems, flight controls, engine controls, etc. The translation from less precise analog devices to digital devices in each of these was readily achieved. In industrial applications, digital control has been employed to a more limited extent in inspection systems and less directly in production control.

In such "closed-loop" applications as process control, a computer compares what *is* happening with what *should be* happening, and issues commands to bring the process into line.

In an essentially different way, computers are being used in "open-loop" applications. The earliest such applications have been to machine tool control in a half dozen widely publicized devices, including the MIT tape-programmed vertical mill, Arma Corporation's ArmaMatic lathe, and the Lewis Flight Propulsion Laboratory turbine-blade lathe. In each of these the control quality exploited is flexibility. Each machine is used in a job-shop sense. It must turn out a variety of products, and conversion from one product to another is simply a matter of programming. In some instances the actual program is prepared in advance and fed to the machine, whereas in others the computer is an integral part of the device and only a small set of instructions.

Here again the computer's innate capacity for generating and storing vast amounts of information is of great importance, and again reproducibility of results to very tight tolerances is imperative. Our concern with comparing the computer to a human operator must creep into the "open-loop" situation too. Here the "optimum" programming, for example in the machine tool operation, is derived from extensive human experience. Cutting speeds, depth of cut, temperature, and knowledge of tools, materials, and products are the joint knowledge of the tool engineer, the set-up man, and finally the operator. The extrapolations from this knowledge necessary to meet new problems again poses an overwhelming challenge to the computer. But the need for flexible and reproducible programming makes this a welcome challenge. Although the machine tool industry is reticent concerning its trade secrets, extensive development work along these lines is undoubtedly under way.

A Look Ahead

What does the future hold for computing machines in the control field? Considering the short span of ten years during which electronic digital machines have been developed and the slightly longer history of analog machines, their applications have already produced remarkable effects. The straightforward use of these devices in computation for engineering purposes is indispensable in major laboratories throughout the country. Certainly this application will expand as more men are trained and more machines become available at reasonable prices.

New and widespread applications for analog computers in direct simulation, both with and without other hardware components, are bound to develop for both design and operational training purposes. Almost anyone who has had an opportunity to work with analog computers quickly becomes conscious of the highly realistic "feel" one develops for the analogued problem.

Among applications of computers for control in "closed-loop" systems, the immense problems of continuous flow processes and distribution systems

"Conceivably, the machine may 'learn' certain responses

Computer Aptitudes for Various Applications

Flexibility: *Can it change programs easily?*
Accuracy: *Is it consistent?*
Speed: *Does it process information rapidly?*
Capacity: *Can it handle lots of complex information?*

	DIGITAL	ANALOG
Computations		
Flexibility	Unlimited	Extensive
Accuracy	Unlimited	Limited
Speed	High	High
Capacity	Extensive	Limited
Usefulness	Very wide	Increasing rapidly
Data Handling		
Flexibility	Unlimited	Limited need
Accuracy	Limited only at input	Limited
Speed	Limited by input	High
Capacity	Moderate	Moderate
Usefulness	Limited by input and storage in many applications	Wide for small problems
Simulation		
Flexibility	Need may be small	Need may be small
Accuracy	Limited at input	Adequate
Speed	Very limited	High
Capacity	Moderate	Extensive
Usefulness	Limited by speed	Wide
Closed-Loop Control		
Flexibility	Need may be small	Need may be small
Accuracy	Unlimited	Limited
Speed	Inadequate for many applications	Inadequate for complex problems
Capacity	Inadequate for many applications	Inadequate for complex problems
Usefulness	Limited by lack of formal understanding of processes	Limited in large processes
Open-Loop Control		
Flexibility	Unlimited	Limited
Accuracy	Unlimited	Limited
Speed	Moderate	Limited in special cases
Capacity	Extensive	Adequate
Usefulness	Being widely pursued	Wide for small problems

from the human operators."

appear outstanding. The application of digital computers to centralized scheduling of power distribution has been widely discussed in the industry. In this instance as in almost all others, both the technical demands of system loading and the economic variables of power source costs must enter into the control relations. Considerable efforts are being expended in the analysis of the engineering and economic factors, and their ultimate reduction to usable mathematical terms insures the final use of high-speed computers.

The more complicated problem of continuous process control in refinery or chemical processes requires similar extensive study. Although the computer may be inadequate for wholly replacing the human operators in such processes, the machine may "learn" certain responses from the human operators and then improve on these differentially. Once again, the possibility exists of seeking out and subsequently reproducing optimum configurations in the control pattern.

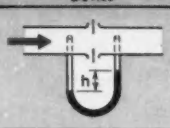
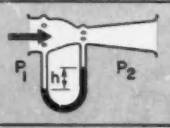
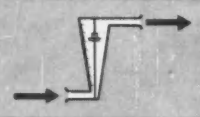
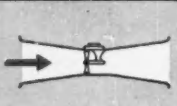
A similar "learning" process has been applied to at least one open-loop machine tool control device, the General Electric experimental record-playback engine lathe. Here the skilled lathe operator goes through his usual steps in both setup and control of turning a single piece. His every action is recorded on magnetic tape. For subsequent pieces the tape is played back and identical operations are performed without the operator. Such a system offers many opportunities for extension. An elementary error computer operating with the operator's initial program, tool replacement data, and inspection data may correct itself throughout any length of production cycle and still lend itself to highly flexible operation. Today such a tool as the General Electric lathe should have infinite applications in the backward areas of the world where skilled labor is at a premium. Carrying the concept to its logical extreme, factories equipped with such automatic devices could "create" new factories.

For the distant future one can visualize entirely new and different production systems based on computer applications and programming techniques. With general-purpose programmed tools such problems as replacement parts inventories may be radically altered in nature. The field distribution depot in such a case may become a small plant operating with a "punched card" deck to produce replacement parts as they are needed.

Perhaps the most important obstacle to more rapid application of these new techniques derives from the shortage of people highly skilled in the use of computers. To date military applications have absorbed the efforts of many of the best-trained and most experienced technicians. As more people are trained and if, more happily, skilled men may concentrate their full talents on peacetime pursuits, the promise may be fulfilled.

SIX VOLUMETRIC LIQUID METERS

Table 1

Device	Operating Principle	Remarks	Cost Range
	**ORIFICE** Differential pressure across restriction is proportional to square of flow rate.	Inexpensive. Fits between standard flanges; h from <1′ to 5′	Device plus transmitter: $350-$450 in sizes up to 8″ diameter.
	**VENTURI** Differential pressure across restriction is proportional to square of flow rate.	High pressure recovery. Meters suspended solids. Suitable for extremely large capacity.	Device plus transmitter: $600-$1200 in sizes up to 8″ diameter; short cones.
	**AREA METER** Constant differential, variable area. Position of bob is calibrated against flow rate.	Self-contained.	Device plus transmitter: $350-$800 in sizes up to 4″ diameter.
	POSITIVE DISPLACEMENT METER Shaft rotates at a speed proportional to flow rate.	Measurement highly accurate. Self-compensating for temperature. Operating head as high as 20 psi.	$100-$3,000 in sizes up to 8″ diameter.
	**VELOCITY METER** Turbine in Venturi section rotates at a rate proportional to flow rate.	Low pressure loss. Satisfactory for temporary overloads. Subtracts reverse flow.	$200-$500 in sizes up to 8″ diameter; add $200 for pilot valve.
	ELECTROMAGNETIC FLOWMETER Conductive liquid induces an e.m.f. proportional to flow rate.	No pressure loss. No viscosity or density effects. Linear calibration.	Device plus instrument containing power supply: $1,500 up to 4″ diameter.

What's Available Today For

Proportioning Liquids

AUTOMATICALLY

LAWRENCE LOWY B-I-F Industries

THE GIST: As process engineers replace outmoded batch manufacture with continuous processing, they look to the control engineer for new ways to mix liquids automatically, accurately, and cheaply. Proportioning liquids by volume is generally cheaper; by weight can be more accurate. Before deciding which of the many proportioning schemes to adopt, the engineer must ask: "What kinds of liquid am I handling? What accuracy do I insist upon? And how much am I willing to spend?" This article describes commercially available equipment that can handle the job and points up the factors the engineer should weigh before he makes his decision.

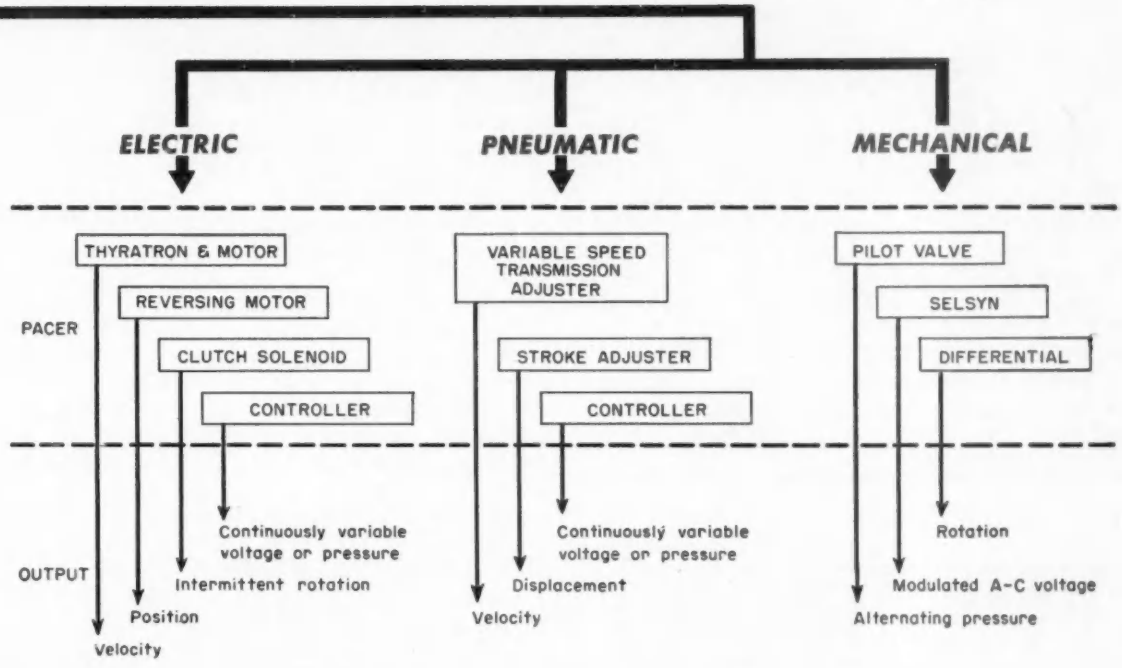
Accurate proportioning is vital to every continuous chemical process. Whether ingredients are combined in a chemical reactor or blended in a mechanical mixer, they must be fed into the process in the proper ratio.

The engineer who designs the proportioning equipment must first know the form of the ingredients. Then he must select equipment that will meter and feed them within specified tolerances. His aim is to minimize three factors 1) handling, 2) conversion of material from one state to another, and 3) cost.

The mechanical controller in Figure 1 illustrates the application of feedback control to continuous proportioning. Primary and secondary feed rates are measured and converted to mechanical rotation in

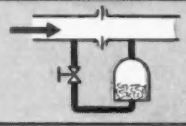
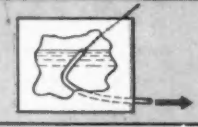
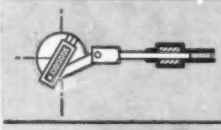
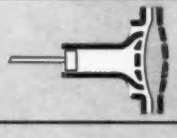
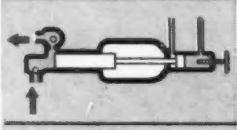
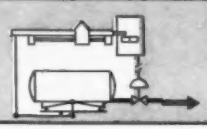
WAYS TO PACE FEEDERS

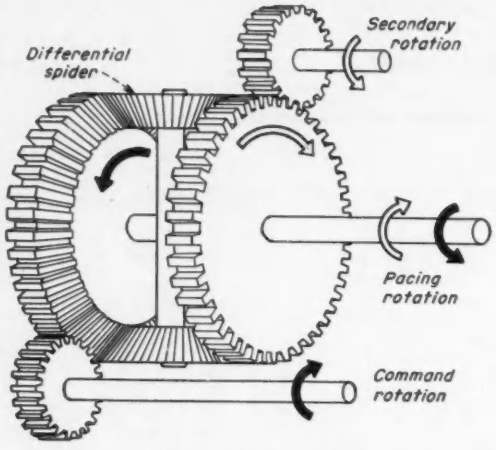
Chart 1



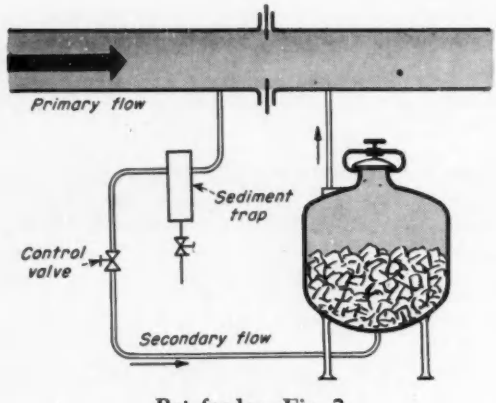
SIX LIQUID FEEDERS

Table 2

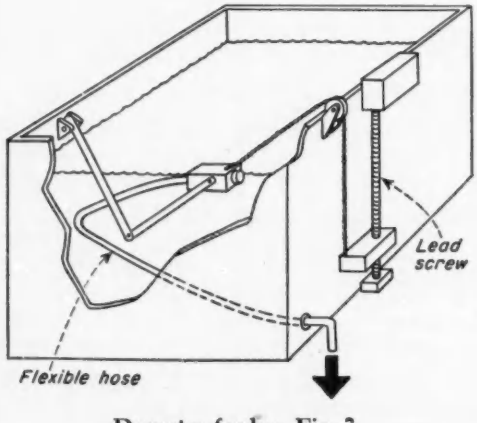
Device	Operating Principle	Remarks	Cost Range
	**POT FEEDER** Differential across restriction carries contents of pot into main line.	Low cost; simple. Used where proportioning is not critical.	Less than $150.
	**DECANTER** Swing pipe or outlet line is lowered into solution tank at required rate.	Low cost; simple.	Less than $250.
	**PLUNGER PUMP** Fluid displacement is constant for each stroke of reciprocating plunger.	Suitable against high pressure. Adjustable rates. Accuracies of ±1%. Negligible slip.	$200 to $1,500. Higher prices for extremely high discharge head.
	**DIAPHRAGM PUMP** Fluid displacement is constant for each stroke of diaphragm.	Suitable against high pressure. Adjustable rates. Accuracies of ±1%. No slip.	$200 to $1,500. Higher prices for extremely high discharge head.
	**FLUID DRIVEN PUMP** A fluid alternately applied to either side of drive piston provides stroking.	Stroking speed constant. Constant clearance-volume.	$1,000 to $2,000.
	**LOSS-IN-WEIGHT** Balanced tank scale poise retracted at desired rate.	Accuracy of 1/4% by weight, independent of temperature, density, viscosity.	$5,000 to $15,000.



Geared differential proportioning controller. Fig. 1



Pot feeder. Fig. 2



Decanter feeder. Fig. 3

opposite directions. The primary feed rate measurement is corrected by the ratio that is to be maintained between the two feeds. The rotation thus developed is the command, or set point, for the secondary feed. Deviation from the set point, indicated by unbalance in the speeds of the two gears, makes the spider move in the direction of the faster gear at a rate proportional to the unbalance. The spider shaft actuates a feeder control device directly or with the aid of intermediate power amplification. By cascading geared differential proportioning controllers, a multiplicity of ingredients are proportioned. Where such a feeder as a positive displacement pump can hold an accuracy within one per cent, the feedback measurement of secondary feed rate is often eliminated.

Liquid Proportioning

Probably the simplest and oldest automatic proportioning liquid feeder is the pot type illustrated in Figure 2. The pot is preloaded with lump or brick chemicals which dissolve slowly and at a steady rate. An orifice or similar restriction in the primary flow line develops a head proportional to the square of primary flow. As long as the secondary flow system also follows the square law, the secondary flow is uniformly proportional to primary flow. The setting of the control valve determines the fraction of primary flow which is diverted through the pot. Given a brick chemical with a steady-rate solubility, the pot feeder maintains a feed of secondary chemical in definite ratio to primary flow. The method is straightforward but not too accurate. Chemicals with steady-rate solubility are not very prevalent; channeling of the bed may occur; high feed rate demands an excessively large feeder; corrosion or build-up on the orifice and control valve alter the proportion of the secondary feed.

Liquid Meters

Table 1 lists volumetric liquid meters. The differential developed across the orifice or venturi is applied to a float-in-mercury instrument, an expandable bellows, or a force-balance device. The square root of the differential is transmitted pneumatically or electrically to pace secondary feeders. Differential meters are not particularly suitable for viscous liquids or slurries. Changes in specific gravity require compensation, and deposits on the edges of orifice plates introduce errors. Despite these specific drawbacks, the differential meter is extremely useful.

Viscosity and pressure variations change the volumetric efficiency of the displacement meter because of the clearances between moving parts.

Liquid Feeders

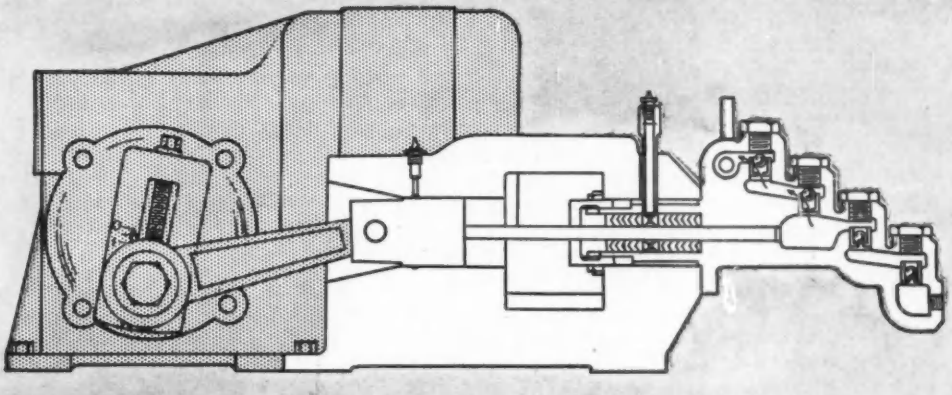
The swing pipe or decanter feeder sketched in Figure 3 is simple. A tank of chemical solution is equipped with a weir or swing pipe which is lowered

at a rate proportional to the pacing signal. The tank can be equipped with an agitator when handling a slurry. An outside weir box overcomes the errors produced by the resulting wave action. The system operates only on gravity feed.

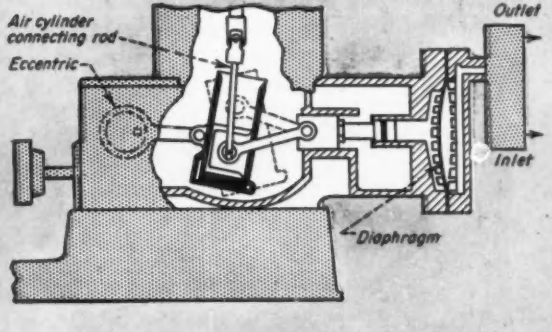
The positive displacement plunger pump is probably the most dependable liquid volumetric feeder. A pump, typical of those built by recognized concerns in the field, is shown in Figure 4. Capacities range from a fraction of a cubic centimeter per minute to 50 gallons per minute. Delivery is varied by controlling the stroking frequency or by adjusting the plunger stroke length. The calibrated crosshead guide indicates stroke setting. Normally the pumps are guaranteed to maintain delivery within one percent of setting over a ten-to-one range. Flow pulsations produced by the reciprocating plunger are reduced by surge changers or by proper timing of the strokes of two, or even three, pumps. The parts of the pumps in contact with the feed fluid are available in special metals, rubber, plastic, or ceramic.

A diaphragm replaces the solid plunger in the pump exhibited in Figure 5. Elimination of chemically-inert packing is the chief advantage of this unit. The diaphragms are made of neoprene or rubber. Recently, plastic and special metal alloys have been used effectively.

The pneumatically or hydraulically powered metering pump illustrated in Figure 6 is a modification of the motor-operated pump. Alternate admission and discharge of air or oil through ports A and B oscillates the driving plunger or diaphragm. A reciprocating pilot valve (not shown) directs the flow of actuating fluid. Driver motion is limited by stop C, set for zero to maximum stroke by the micrometer-threaded shaft running from the stop to the handwheel D. A counter geared to the shaft reads stroke in increments of one-hundredths of an inch. Dashpots with adjustable ports smoothly cushion the driver at the end of each stroke. An

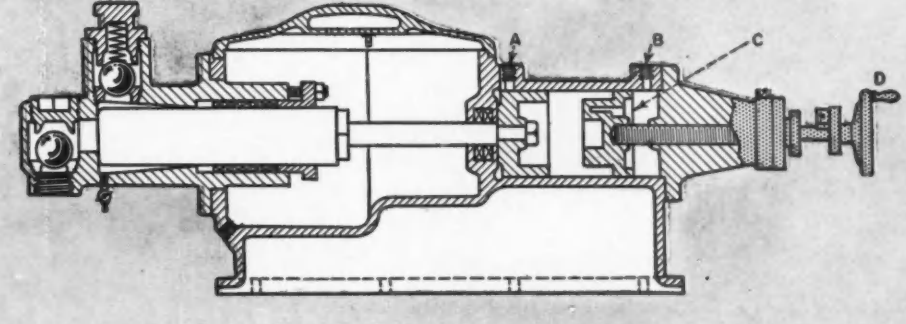


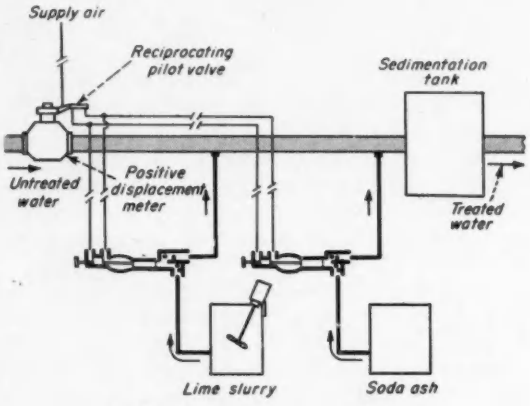
Decanter feeder. Fig. 4



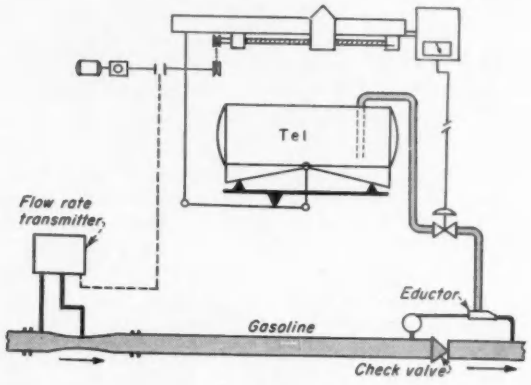
Positive displacement plunger pump. Fig. 5

Positive displacement diaphragm pump. Fig. 6





Water treatment system. Fig. 7



Proportioning of TEL to gasoline. Fig. 8

inert fluid seals the chamber between driver end and reagent end to prevent exposure to air and the consequent corrosion or build-up on the plunger.

Crank-driven and fluid-driven metering pumps have a basic difference: the ratio of total displacement volume to clearance volume varies in the former as stroke is changed but remains constant in the latter. A fluid-driven unit is unaffected by low frequency; each stroke is made at the same speed regardless of frequency. Because viscosity alters time required to fill the cylinder, the stroking speed must not be so fast that the plunger starts to withdraw fluid before the cylinder is full.

Figure 7 shows the application of proportioning equipment to the treatment of water with lime slurry and soda ash. The proportioning pumps are the pneumatically-powered type shown in Figure 6. The pilot valve is oscillated at a frequency proportional to the measured flow of untreated water, causing the pumps to stroke at the same frequency. The proportions of lime slurry and soda ash to water flow are independently adjusted by setting the driver stops.

Gravimetric Liquid Feeding

A continuous gravimetric feeder performs four basic operations: The feed material is suspended in a hopper, supported on a weighing platform, or carried on a traveling belt. The suspended load is sensed and transmitted by a scale lever system. Load deviation from set load is counteracted to maintain the system in balance. The balancing force activates the control element that paces the feed.

Figure 8 shows how a gravimetric feeder adds tetraethyl lead to gasoline. The principle is applicable to any liquid proportioning problem which demands extreme accuracy.

The complete contents of a railroad tank car containing 8,500 to 15,000 galons of TEL are pumped to a horizontal tank standing on a scale platform. Levers connect the platform to a scale head which provides an accuracy of one pound in 10,000 pounds. A variable-speed drive determines the TEL ratio, not more than three cubic centimeters per gallon of gasoline. Through a clutch the drive rotates a finely threaded poise-retracting screw. A gasoline flowmeter transmits to the clutch an intermittent electric signal, of 0 to 13.3 seconds duration every 15 seconds. In this way the poise retracts a distance proportional to the gasoline flow in each 15-second interval. As the poise travels back along the screw, the scale beam unbalances. A linkage at the tip of the scale beam senses the unbalance and responds by altering the output air pressure of a controller. The pneumatic signal is applied to a diaphragm motor valve located in the TEL suction line. Following a retraction of the poise, and beam unbalance, the valve opens, lightening the tank and re-establishing null balance. The sensing and response are so rapid that an extremely smooth movement takes place when the gasoline flow varies.

The equipment in actual operation has provided a finished product having an accuracy of plus or minus 0.008 cubic centimeters TEL (by chemical analysis) per gallon of gasoline for doses of 0.5 to 3 cubic centimeters per gallon.

This same arrangement is used in continuous production of soap detergent. Oleum, fatty oil, and glycerine are all fed by weight on the same loss-in-weight device described. But there is no time out for loading every time a weigh tank runs down. Instead, there are two scale-mounted tanks, each having sufficient capacity for a four-hour run. The tanks are shifted by a lever arm when one is nearly empty.

In the October issue of CONTROL ENGINEERING *Mr. Lowy will cover equipment for the automatic proportioning of solids.*

NEW TECHNIQUES FOR

Hydraulic Servo Design

Because of their low weight-to-power ratio, high speed of response, and reliable performance, hydraulic position-control servos with cylinder type actuators are used as the main power amplifiers in many control systems. Here is a new way to determine basic design parameters.

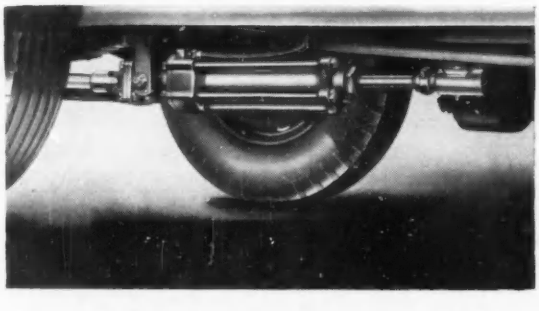
JAMES M. NIGHTINGALE, Manchester, England

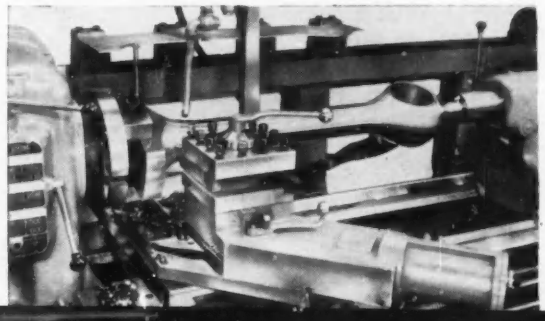
DESIGN PARAMETERS FOR hydraulic position-control servos with cylinder-type actuators can be divided into roughly two groups, those that relate to overall system response, and those that affect stability. Investigation of the latter involves a thorough dynamic analysis of the unit and its mountings. Since this is often a difficult task and the results are not always reliable, it is usual to leave certain parameters for adjustment, so that the unit can be tuned under actual operating conditions.

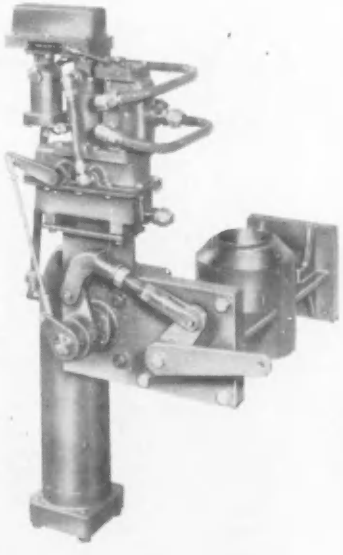
In contrast, a designer can at an early stage determine factors affecting the main operating characteristics by ignoring such destabilizing effects as fluid compressibility and dynamic output loading. The material presented here deals primarily with these basic factors, although the physical realization of cer-

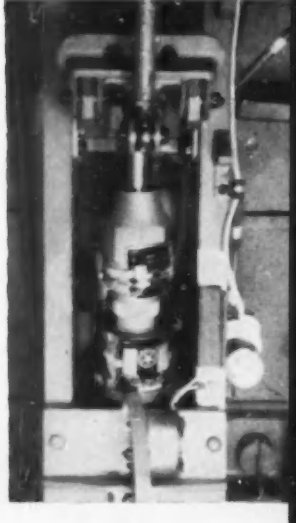
Typical Applications of hydraulic servo amplifiers. Fig. 1

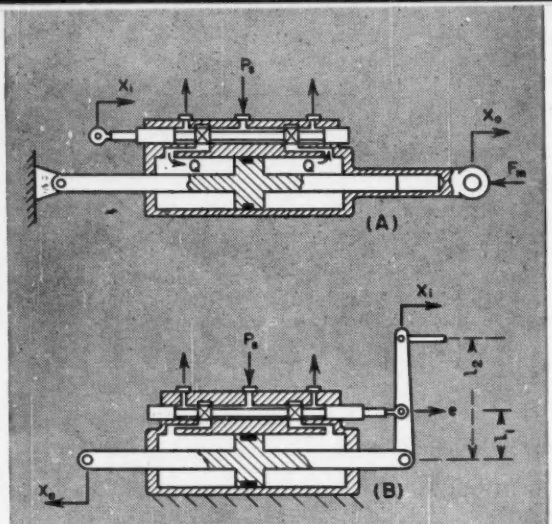
Automobile power steering—*Vickers Inc.* **(below, top)**
Hydraulic valve positioner—*General Regulator Corp.* **(center)**
Machine tool contouring system—*Turchan Follower Machine Co.* **(below, bottom)**
Aircraft control surface actuator—*The Glenn L. Martin Co.* **(right)**



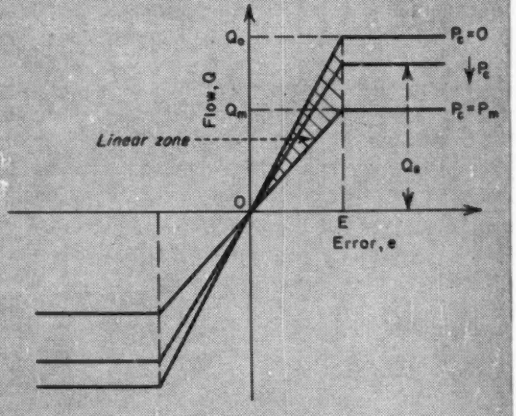






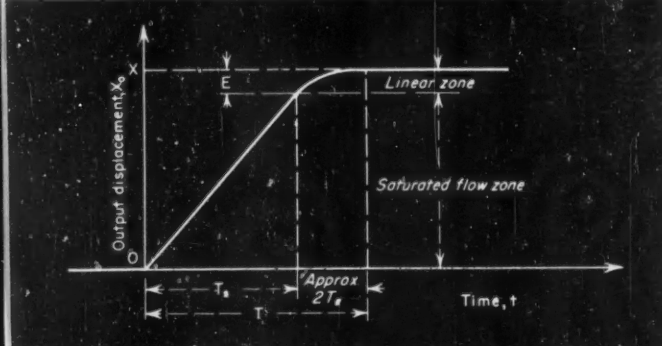


Three closed loop arrangements of a slide valve-cylinder combination. In (A) the valve opening is a direct measure of error, while in (B) the opening error relation depends on the ratio of the differential levers. Fig. 2



Flow variation as a function of error and operating pressure. Linear zone is bounded by maximum valve opening and by pressure corresponding to maximum and no-load conditions. Fig. 3

Output displacement over full stroke of cylinder as a function of time for one load condition. Piston moves at constant saturated velocity until valve starts to shut. Fig. 4



tain stability conditions will be discussed briefly.

Figure 2 shows two typical closed loop arrangements of a slide valve-cylinder combination. The use of negative feedback, either directly or through a linkage connection, ensures accurate input-output relations, with the swamping of inherent nonlinearities and also with suitable stability characteristics. Power amplification is large, since the force accompanying the input or command displacement need overcome only the axial slide-valve forces. The slide valve can take on various configurations; two being the cylindrical construction (as shown) and a balanced plate type construction in which the axial forces are negligible.

In the unit shown in Figure 2 (A), the valve opening is a direct measure of error since the command displacement, X_i, directly actuates the valve stem and since the feedback is one-to-one, with the valve and cylinder bodies moving an amount equal to the output displacement.

In Figure 2 (B), the error-valve opening relationship involves lever ratios, with the relative movement and feedback ratios depending on the ratio l_1 to l_2. The results developed here for the design shown in Figure 2 (A) also apply generally to the units using the lever differentials.

Control systems using this kind of hydraulic servo amplifier are common in industrial and military equipment. Although the specific requirements of certain systems may add to or modify these basic designs, the fundamental operating principles and design factors still apply. Typical applications shown in Figure 1 include automobile power steering, a valve actuator, a machine tool contouring system, and an aircraft control surface actuator.

In power steering, rotation of the steering wheel supplies the input displacement to the valve, while the output displacement positions the tie rod.

The valve actuator consists of two hydraulic servo amplifiers in series, the initial signal being a hydraulic pressure proportional to desired valve position. The first amplifier output displacement drives the second amplifier slide valve, which in turn supplies oil to the main-valve cylinder to position the main valve. This is similar to the units shown in Figure 2 (B), since input and output displacement are compared by means of a linkage differential.

The contouring system guides a tool in accordance with the shape of a template. The slide-valve stem is spring loaded against the template, causing the tool carriage to follow the correct contour as the axial feed drives the input follower along the template.

In the last application, the pilot actuates the slide valve by means of mechanical links and cables from the control stick in the cockpit. The amplifier supplies the power required to position the control surface in accordance with his commands.

The unknown parameters that must be determined are cylinder area, working pressures, pump delivery, valve travel, and port area. These unknowns can be

expressed in terms of known quantities that are fixed by the requirements of a specific application. These fixed quantities are system pressure, cylinder stroke, maximum cylinder load, and various operating times. Usually the unknown quantities are expressed as lumped parameters rather than as separate factors.

To determine the cylinder area, A, a suitable maximum operating differential pressure, P_m, must be chosen. For reasons to be discussed later, P_m is usually fixed at $\frac{2}{3}P_s$. Then

$$A = \frac{F_m}{P_m} = \frac{3F_m}{2P_s} \tag{1}$$

Assuming that the flow through the valve varies linearly with valve opening, flow can be expressed by

$$Q = \frac{Cae}{E}\left[\frac{P_s - P_c}{2}\right]^{1/2} \tag{2}$$

In other words, the flow is equal to the square root of half the total pressure drop across the inlet and exhaust ports times the product of the flow coefficient and the area of opening of the inlet (or exhaust) port. For a wide range of hydraulic fluids and orifice shapes C can be taken as equal to 100, if the quantities in Equation 2 are expressed in English units (lb-in.-sec).

The flow variation with error and operating pressure is shown in Figure 3. From this diagram two important points can be noted:

▶The flow varies with operating pressure and hence with output load. For a no-load condition, the differential pressure, P_c, across the piston is zero (neglecting friction) so that the flow is a maximum for any given error. When the cylinder is driving the maximum load, the differential pressure, P_c, equals P_m so that the flow under this condition is a minimum for a given error.

▶For maximum valve opening the flow saturates. In terms of response this means that when the valve is only partially open, the unit is error-sensitive, but when the valve is fully open, the output moves at a saturated velocity that varies only with output load.

The linear response region in Figure 3 extends to a point where the error equals the maximum valve opening, E. Beyond this point the flow is saturated and depends entirely on operating pressure and load. The saturated flows range from Q_o for no load to Q_m for full load.

Figure 4 shows a plot of time vs. cylinder stroke for one load condition. Starting at one end of the stroke (assuming that the valve opens instantaneously), the piston will traverse the saturated flow zone (total stroke X minus maximum valve opening E) at a constant velocity in a time T_s. The velocity decreases in the linear zone as the valve closes so that a total time T is required to travel full stroke. An increase in load will decrease the slope of this curve (decrease saturated velocity), thus increasing the operating time, while a decrease in load will increase the slope (increase saturated velocity).

NOTATION

x_i—input displacement.
x_o—output displacement.
e—error (valve displacement).
E—maximum valve displacement.
a—valve port area.
E_1—static deflection under full load.
a_1—exposed port area corresponding to E.
A—effective cylinder piston area.
X—cylinder stroke.
F_m—maximum cylinder load.
P_c—cylinder differential operating pressure.
P_m—maximum differential operating pressure.
P_o—minimum pressure in cylinder.
P_s—system pressure.
Q—flow from valve tending to displace cylinder.
Q_s—saturated flow.
Q_m—saturated flow under maximum cylinder load.
Q_o—saturated flow with no cylinder load.
T_m—operating time under maximum cylinder load.
T_o—operating time with no cylinder load.
T_c—creep time.
T_s—system time constant.
k_x—jack stiffness.
k_e—valve stiffness.
N—bulk modulus of fluid.
A_o—area of bleed hole in piston.
K—amplifier gain.
p—Laplace operator.
C—Valve flow coefficient.
ω—frequency.
ω_n—resonant frequency of system.
M—amplitude ratio at resonant frequency.

Within the error-sensitive region, the system equations consist of Equation (2) and the following two relationships.

$$e = x_i - x_o \tag{3}$$

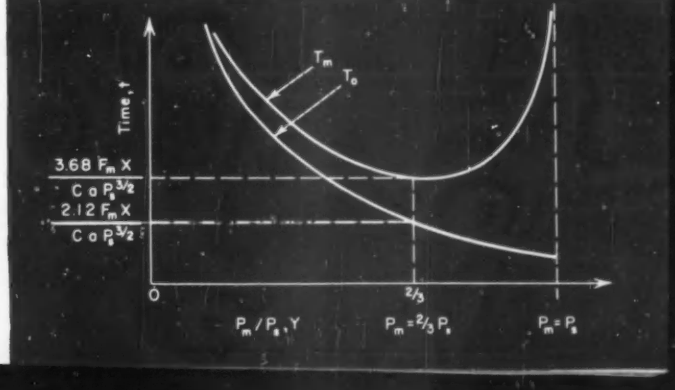
$$\frac{dx_o}{dt} = \frac{Q}{A} \tag{4}$$

These can be combined to give the overall transfer function

$$\frac{x_o}{x_i} = \frac{1}{1 + T_s P} \tag{5}$$

Variation of operating times with ratio of maximum operating to system pressure. Optimum P_m is selected to equal $\frac{2}{3}$ P_s. Fig. 5

Variation of operating times with ratio of maximum operating pressure to system pressure. Optimum P_m is selected to equal $\frac{2}{3}$ P_s. Fig. 5



where the system time constant, T_c, can be expressed by

$$T_c = \frac{EA}{Ca\left[\frac{P_s - P_c}{2}\right]^{1/2}} \tag{6}$$

Assuming that the time required to traverse the linear zone, E, in Figure 3 is twice the time constant, then the total operating time for a half-cycle of full cylinder travel (full stroke in one direction) is approximately given by

$$T = T_s + 2T_c \tag{7}$$

and from Figure 4

$$T_s = \frac{(X - E)A}{Q_s}$$

From Equation (6)

$$2T_c = \frac{2EA}{Q_s}$$

Substituting these equations in Equation (7), the approximate total time can be expressed by

$$T = \frac{AX}{Q_s}\left[1 + \frac{E}{X}\right] \tag{8}$$

where Q_s is the saturated flow for any given differential pressure P_c and is given by

$$Q_s = Ca\left[\frac{P_s - P_c}{2}\right]^{1/2}$$

Equation (8) shows that by reducing the ratio of valve opening to total cylinder stroke, E/X, the capacity of the pumps required to give a specified operating time can also be reduced. Common design values of E/X range from 1/20 to 1/30. Using these alues the output can be considered saturated over the entire stroke, resulting in a nonharmonic frequency response for all frequencies exceeding a critical value. This wave distortion, caused by constant velocity following in the saturated range, is usually less important than power economy and, if desired, the critical frequency can be fixed above the normal operating frequency of the whole system.

The operating time varies with the differential pressure across the piston and is shorter under a no-load condition. Thus, for maximum load where P_c equals P_m

$$T_m = \frac{AX}{Q_m} = \frac{F_m X}{CaP_m\left[\frac{P_s - P_m}{2}\right]^{1/2}} \tag{9}$$

and for a no-load condition where P_c equals 0

$$T_o = \frac{AX}{Q_o} = \frac{F_m X}{CaP_m\left[\frac{P_s}{2}\right]^{1/2}} \tag{10}$$

Rewriting T_m as a function of y in Equation (9), where y equals P_m/P_s and similarly expressing T_o as a function of y in Equation (10).

$$T_m = \frac{F_m X}{CaP_s^{3/2}}\left[\frac{2}{y^2 - y^3}\right]^{1/2} \tag{11}$$

and

$$T_o = \frac{F_m X}{CaP_s^{3/2}}\left[\frac{2}{y^2}\right]^{1/2} \tag{12}$$

The variation of T_m and T_o with y or P_m is shown in Figure 5. A logical procedure is to minimize the operating time under the greatest cylinder load; that is, to make $\partial T_m/\partial P_m$ or $\partial T_m/\partial y$ equal to zero. This is equivalent to making the sensitivity (defined as the ratio of output power to valve port area) a maximum when operating against the greatest output load. This yields an optimum value of y equals 2/3 or P_m equals $2/3P_s$. This is the value used in the previous calculations.

Having determined an optimum value for P_m it is now possible to calculate the valve port area from Equation (10). This relationship is used since usually T_o rather than T_m is specified. Solving this equation for the port area gives

$$a = \frac{3F_m X}{2C\left[\frac{P_s}{2}\right]^{1/2} P_s T_o} \cong \frac{0.02F_m X}{T_o P_s^{3/2}} \tag{13}$$

Maximum flow is encountered under a no-load condition and can be expressed by

$$Q_o = \frac{AX}{T_o} = \frac{3F_m X}{2P_s T_o} \tag{14}$$

If the pump is a constant delivery type, means must be provided to by-pass any excess flow back to the reservoir.

All of the basic quantities have been determined except for the valve travel, E. This parameter controls not only the width of the error-sensitive region, but also the frequency response within this zone. If the input in the overall transfer function, Equation (5), is a sinusoidal displacement, then under a no-load condition a flat-band frequency response is obtained up to a frequency

$$\omega = \frac{1}{2\pi T_o}\left(\frac{X}{E}\right) \text{ cps} \tag{15}$$

Therefore, if ω and T_o are specified, the ratio E/X can be determined. As previously stated, typical values obtained in this way vary between 1/20 and 1/30. An undistorted response with little attenuation or phase lag can be obtained for inputs given by

$$x_i = E \sin\left(\frac{X}{E}\,\frac{t}{T_o}\right) \tag{16}$$

under a no-load condition, and by

$$x_i = E \sin\left(\frac{X}{E}\,\frac{t}{T_m}\right) \tag{17}$$

under a full load.

A summary of relationships that can be used to determine the basic design parameters is given in the following table.

SUMMARY OF BASIC EQUATIONS

Equation No.	(1)	(13)	(14)	(15)
Determines	Cylinder area	Valve port area	Maximum saturated flow	Valve travel
Equation	$A = \frac{3F_m}{2P_s}$	$a = \frac{0.02F_mX}{T_oP_s^{3/2}}$	$Q = \frac{3F_mX}{2P_sT_o}$	$E = \frac{X}{2\pi\omega T_o}$
Controls	Operating pressure	Operating time	Required pump delivery	Response in linear zone

Factors Affecting Stability

Certain parameters associated with the flow characteristics of the unit can be adjusted to limit destabilizing effects both inside the amplifier and in the control system as a whole. However, as a first design approximation, only compliances within the unit itself need be considered. There are three important parameters: the stiffness of the cylinder, the stiffness of the valve and the amplifier gain.

The flexibility in the cylinder is almost entirely caused by fluid compressibility, its stiffness being

$$k_x = \frac{2AN}{X} \tag{18}$$

Since in practical systems there is a certain amount of air suspended in the oil, the bulk modulus, N, of the hydraulic fluid is a function of pressure. For this reason it is important to keep the minimum jack pressure fairly high. This minimum pressure, P_o, is given by

$$P_o = \frac{P_s - P_m}{2} \tag{19}$$

so that P_m should not be too high. The figure P_m equals $2/3P_s$ (already established for minimum operating time under maximum load) is usually satisfactory. For example, if P_s equals 3,000 psi, then P_o equals 500 psi. At this value, N is usually about 200,000 psi which establishes k_x at a high enough level in lb per in. to have limited effect on system stability. By means of small leakage paths on either side of the valve lands, Figure 6, a base pressure is maintained on both sides of the piston even under a no-load condition.

The stiffness of the valve, when $Q = 0$, is given by

$$k_v = A\left(\frac{dP_c}{de}\right) \tag{20}$$

or the load on the cylinder required to move the valve a unit length is equal to the change in cylinder load, AdP_c, divided by the corresponding change in valve displacement, de, for a no-flow condition. Theo-

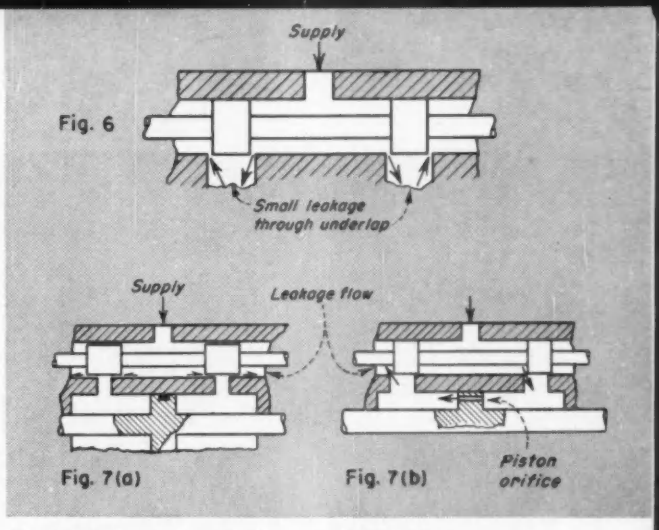
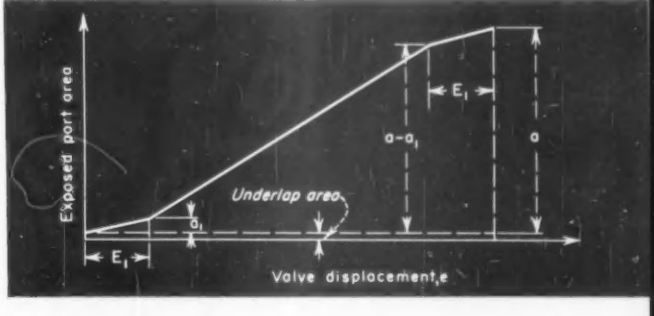


Fig. 6

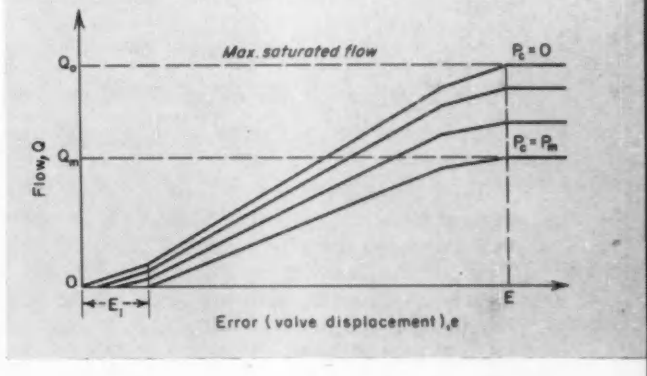
Neutral leakage past valve lands maintains base pressure on both sides of piston even under a no-load condition. Fig. 6

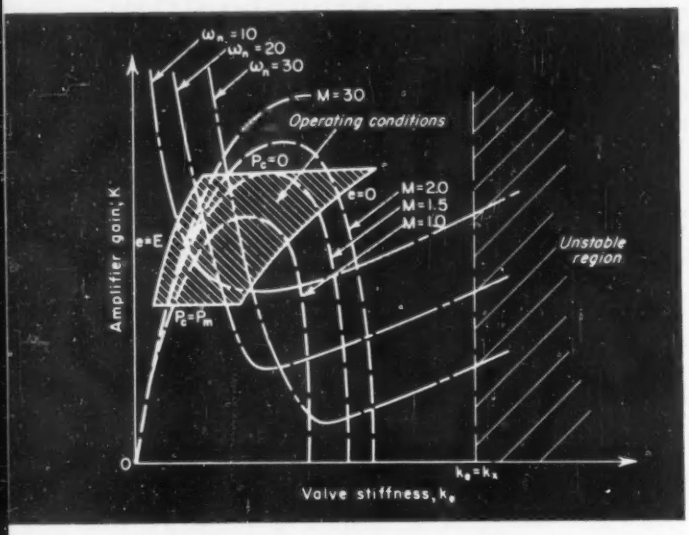
Hydraulic potentiometers. Valve overlap shown in (A) is unsatisfactory because of variation of flow with temperature. Use of bleed hole in piston, (B), and modified valve characteristic is better. Fig. 7



Modified valve displacement versus port area characteristic used with bleed hole in piston to reduce creep time. Fig. 8

Modified flow curve obtained with valve characteristic shown in Fig. 8. Note reduced flow with displacement region, E_1, at each end of valve stroke. Fig. 9





Plot of K-K_e plane showing quiescent operating conditions superimposed on the stability characteristics of system. ω_n represents the resonant frequency of system and M the amplitude ratio at resonant frequency. Fig. 10

retical stability considerations lead to the criterion.

$$k_e < k_x$$

This can be explained physically as follows. A change in load tends to shorten the column of oil in the cylinder. The valve must then open sufficiently, because of cylinder displacement, to allow a differential pressure to built up in the cylinder to balance the change in load. Failing in this, the valve would overcompensate the cylinder displacement, further compressing the fluid column and setting up a self-maintained oscillation. Thus valve stiffness must be less than cylinder stiffness to permit proper compensation for changes in loading.

From Equation (18) it can be determined that under full load the unit will deflect at least an amount E_1 which can be calculated as follows

$$k_x = \frac{F_m}{E_1} = \frac{2AN}{X} \tag{18}$$

Substituting

$$\frac{F_m}{A} = P_m = 2/3P_s$$

from Equation (1), the following result is obtained

$$E_1 = \frac{XP_s}{3N} \tag{21}$$

This is the static deflection, which may be exceeded under a fluctuating output load. Output flexibility can be serious from the viewpoint of system stability with respect to a varying output load; however, it is unavoidable. Its destabilizing effects can be reduced by limiting the so-called creep velocity with which the cylinder connects for change in load.

Valve flexibility can be obtained by the use of a hydraulic potentiometer, Figure 7, which causes a slow change in valve resistance at the beginning of the valve stroke and consequently a low creep velocity. The use of valve overlap, Figure 7 (A), is not satisfactory, partly because of the variation of flow with viscosity and hence with temperature. For the unit with a piston leak, Figure 7 (B), a low creep velocity is obtained by modifying the flow characteristics of the valve, which hitherto have been assumed linear. This can be done if the valve port consists of a group of small holes that are exposed to give an exposed port area varying with displacement as shown in Figure 8. The steady flow loss obtained with the piston leak design is several times smaller than that resulting from overlap.

Equating the steady flow through the valve (caused by valve opening to area a, as a result of static deflection E_1) and through the bleed in the piston under full load leads to the following expression for the area of the hole in the piston

$$A_o = a_1 \left[\frac{P_s - P_m}{2P_m} \right]^{1/2} = \frac{1}{2} a_1 \tag{22}$$

The time required to creep under maximum load depends on the area a_1, according to the relation.

$$\frac{a_1}{a} = \sqrt{3} \frac{P_s}{N} \frac{T_o}{T_c} \tag{23}$$

In practice T_c is about equal to $T_o/2$, and therefore the unit attenuates for fluctuating loads at frequencies near the normal operating condition. Use of the relation T_c equals $T_o/2$ yields

$$\frac{a_1}{E_1} \leqq 0.35 \frac{a}{E} \tag{24}$$

which together with Equation (21) defines the curve of modified valve port area versus displacement, Figure 8. Figure 9 shows the flow versus error curve for this condition.

The last of the three parameters, amplifier gain, controls the relative rather than the absolute stability of the unit. It is defined, when P_c is a constant, as

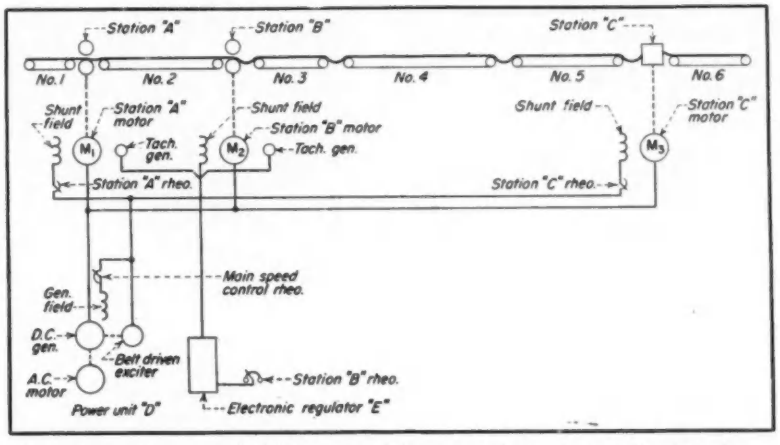
$$K = \frac{1}{A} \left(\frac{\partial Q}{\partial e} \right) \tag{25}$$

or amplifier gain represents the change in piston velocity with a change in valve displacement for a constant load condition.

Actually K and k_e are not constants but are in fact functions of e and P_c. Thus the response characteristics vary at each point in the linear zone and for each value of output load. By calculating K and k_e for each possible operating condition, a domain is defined on a K–k_e plane, Figure 10. The stability characteristics of the whole system can be superimposed on this plane. The flow curve can be adjusted to meet the system requirements.

Controlling Tension of Plastic Sheet

This simple and inexpensive system enabled a manufacturer to switch from manual to automatic control. The controls turn out a better product, in larger quantities, and at lower cost.



Electronic regulator controls field of motor M2 to maintain constant speed ratio between stations A and B. Fig. 1

A manufacturer whose operation involved batch processing of plastic sheet materials wanted to change from manual to automatic control. Anderson-Nichols & Co., Boston, designed a system which kept the cost of controls to a minimum, yet increased production, provided closer quality control, and reduced scrap and manufacturing costs.

One of the problems in applying automatic control was the close speed regulation required between the processing stations and the conveyors to prevent stretching and breaking of the material.

Figure 1 shows the general schematic layout of the main process mill and drive, with the conveyors.

MAIN PROCESS

Requirements for automatic controls were:

- Speed control on each individual motor.
- Constant speed ratio between rotary elements at stations A and B for the various types of loads.
- This ratio had to be adjustable.
- All motors had to be started from one push button.
- Jog reversing was necessary for stations A and B.
- Emergency stopping of the whole train was required.
- All motors needed dynamic braking.
- The drive for Station C had to have manual adjustment at the operator's position.

OPERATING STATIONS

Station A performs a continuous operation on the material and is driven by a 75-hp, 230-vdc, adjustable-speed motor (M1).

Station B is similar but with a 25-hp, 230-vdc, adjustable-speed motor (M2).

Station C performs an intermittent operation on the material and is powered by a 25-hp, 230-vdc, adjustable-speed motor (M3).

The power unit D is an electronic speed variator motor-generator set, rated at 150 hp and 480 volts. The ac induction motor drives a dc generator and an exciter. Control devices, electronic regulator, and protective relays are all inclosed with the generating unit in one cabinet and force-ventilated with filtered air.

The electronic regulator E is simply an amplifier and rectifier which is used to control the shunt field of the motor M2 by means of tachometer feedback.

OPERATION

The motor-generator set is started by a push button at the operator's station. The belt-driven exciter supplies the main generator field, the field of motor M1, the field of motor M3, and the control voltage.

The operator then presses the "run" button which starts the motors. They come up to the speed selected by the setting of the main speed control rheostat, which is in the main generator field and located on the operator's control panel.

Fine speed adjustment is obtained by individual trimming rheostats. The motor M2 is kept at the selected speed by the electronic regulator. The regulator receives feedback signals from tachometer generators connected to the shafts of the motors. The difference in the two signals is amplified and controls the output of the rectifier which in turn supplies the field of Motor M2. (This type of operation is satisfactory since the operational speed range is normally less than 2-to-1, and the ratio from B to A is practically unity). For example, if motor M2 tends to speed up, the signal from its tachometer generator increases. This causes a greater unbalance in the regulator, and the rectifier output is thus increased. This in turn increases the field of Motor M2 and slows down the motor until the signals balance. The operation of the third motor M3 is described under the operation of conveyors.

CONVEYOR SYSTEM

The process conveyors between Stations B and C are 100 ft long. The length and weight of the sheet material made it necessary to power drive the conveyors and regulate the speed of all three sections.

The three conveyors are each driven by a constant-speed ac motor. The belts are controlled by electrically operated mechanical speed variators with a 4-to-1 speed range.

Figure 2 shows the wiring schematic of the speed control for the conveyors. Operation of the system is as follows:

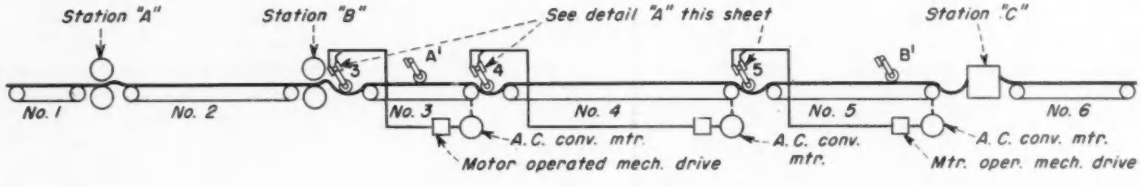
1. With no material on the conveyors, limit switches A′ and B′ are open. This opens the circuit to the speed-adjusting controls on the three conveyors. The operator threads the sheet through the three conveyors by holding down the by-pass button, adjusting the speeds of all three conveyors by means of the fast and slow push buttons.
2. With the sheet running through all the conveyors and into Station C, and with the whole train up to desired speed, the operator releases the by-pass button. The three limit switches controlling the loops between the conveyors are energized by the closing of the switches A′ and B′. These switches are closed by the sheet.
3. As long as sheet material is moving on the conveyors, speed adjustment is automatic. Take conveyor 3 as an example—if the loop grows in size, contact CF3 closes. This moves the adjustable control to increase speed on conveyor 3 which in turn decreases the size of the loop. As soon as the loop moves back to its original size, contact CF3 opens and the control stops. If the loop gets too small, the conveyor is running too fast and the sheet opens switch CS3 which slows down the conveyor.
4. An adjustable time-pulse relay prevents oscillation. The contacts of this relay make momentary contact every ten seconds. Any CF or CS contacts which are closed at the time of contact receive an impulse for the duration of the relay closing. Thus the controls are "inched" until the desired positions of the controls are reached.
5. As the end of the sheet tails through the beginning of the conveyor at Station B, limit switch A′ opens and cuts off the power to the three loop-control switches. This "freezes" all three mechanical speed variators at their respective ratios so that the system remains in proper adjustment and ready for threading of the next sheet.

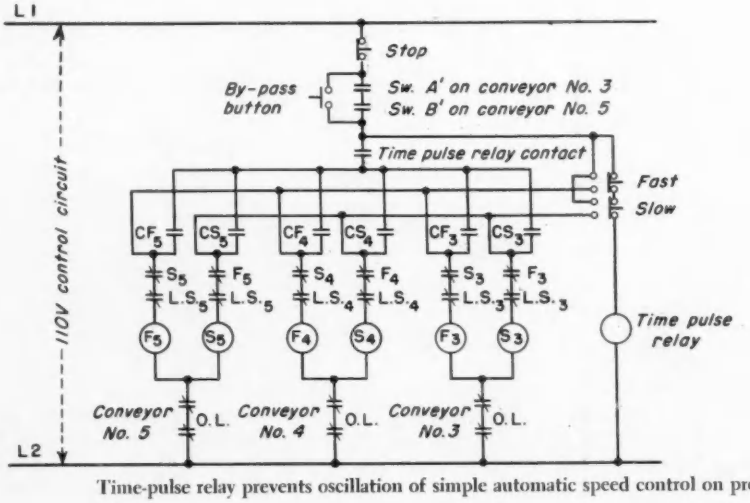
Control is also required at Station C. This drive is powered by a motor operating from the main dc supply and the speed closely follows that of the output of Stations A and B. A field rheostat at the operator's station permits fine adjustment and allows for shrinkage of the material as it cools along the conveyors. With this rheostat, the operator can control the loop at the end of the conveyor section adjacent to Station C.

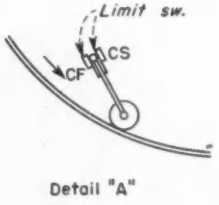
The process train needs little attention once the mill is started and speeds are adjusted. It will maintain its speed ratios with only an occasional trimming of speeds of the various motors in the train. The automatic controls require practically no judgment on the part of the operator. They turn out a much better product, in larger quantities, and for less money than the manual controls.

The use of simple switches as the basic control element, with the time-pulse relay preventing overcontrol, allowed inexpensive construction of a closed-loop control system for the three conveyors. Since only slow changes in conveyor speed were required by the process, the use of motor-driven mechanical speed variators in an on-off type of control system was permissible. The time-pulse relay is the least expensive way to assure stability in such a system.

A realistic design approach to the processing-station drive system, in keeping with the precision required by the process, led to driving three dc motors from the same variable voltage source. Speed equalization was provided by the inexpensive trimming rheostats. A simple amplifier-rectifier type electronic regulator provided close, continuous control at the critical station. The whole control system is a complete, yet economical, solution to the problem concerned.







Time-pulse relay prevents oscillation of simple automatic speed control on process conveyors. Fig. 2

Is automation in your future?

Any consideration of automation quickly reveals one outstanding fact. It is that success or failure in automation depends to a great degree on the ingenuity and skill of control engineers. Automatic electrical control is the heart of automation.

This explains why capable management invariably brings such talent into consultation in even their earliest exploratory discussions of automation. Why Cutler-Hammer engineers have already assisted in bringing automation to breath-taking reality in such diverse industries as paper, glass, cement, rubber, sugar, steel pipe, wire and automotive.

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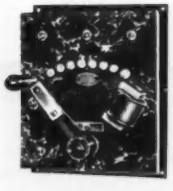
Automation may hold tremendous opportunities for your company in production economies and product uniformity. But it requires a large investment in engineering before a greater investment in equipment. Cutler-Hammer experience can safeguard both. It avoids costly false starts, prevents impractical or needlessly complicated constructions and frequently points the way to unsuspected automation possibilities. Write or wire today. CUTLER-HAMMER, Inc., 1467 St. Paul Avenue, Milwaukee 1, Wisconsin.



The "Kitty Hawk" of Automation

The very first automatic feature in motor control was the no-voltage release in the Cutler-Hammer Bulletin 10 Starter of 1892. The starter handle was held in the "on" position by an electromagnet and returned automatically to the "off" position whenever the power supply failed. This protected men at machines from sudden unexpected restarting, motors against burn-out due to the inrush of uncontrolled current.

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In the aircraft industry, as in many other engineering applications, the Remington Rand ERA 1103 Electronic Computing System has proven how easily it can handle the most difficult research problems. Here are some reasons why leading aircraft builders and other prominent users are counting on the ERA 1103 these days:

Because of its ability to reduce large volumes of data at extremely high speeds, the ERA 1103 is the ideal computing system for scientific applications. Its speed is matched by many other outstanding characteristics: superb operating efficiency, obtained through large storage capacity...great programming versatility...the ability to operate simultaneously with a wide variety of input-output devices...and far greater reliability than any computer in its class.

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ELECTRONIC COMPUTER DEPARTMENT, Remington Rand Inc. ROOM 1982, 315 FOURTH AVE., NEW YORK 10,

Unitized Controls for Atomic Piles

SEYMOUR OESTRETCHER, American Machine & Foundry Co.

A recent study of research reactors has led to the development of unitized reactor control components. The components are unitized to provide great flexibility in application to reactor controls. The resulting standardization lowers cost and increases reliability and safety.

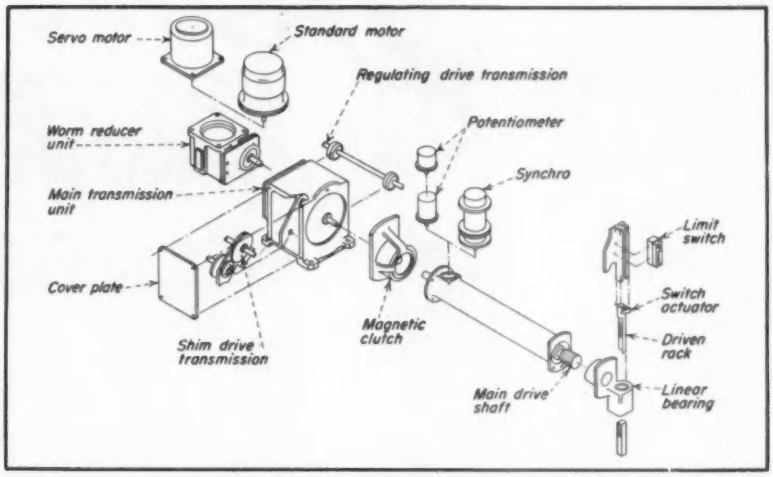
Unitization has been applied to the rod drive mechanism components of the reactor control system, including gear reducers, transmissions, clutches, and rack-and-pinion drives. These mechanisms are applicable to a wide variety of reactor control systems. On-off control systems or proportional control systems with or without automatic resetting (integral control) or rate sensitivity are possible variations. As widely different as these systems may be from the control engineering point of view, they can be applied to the reactor easily with the new units.

These unitized mechanisms can be used on all reactors, including research facilities, controlled by the insertion of rods of high neutron absorption cross-section. Each specific application must be passed upon by the AEC Advisory Committee on Reactor Safeguards. Reactor power output is controlled by positioning the rods, increasing as the rods are withdrawn. These rods, known as poison rods, fall into two categories: safety-shim, and control, or regulating, rods.

The safety-shim rods should have a combined control effect of several times the maximum excess reactivity in the reactor. They serve a dual purpose. As safety rods they are withdrawn at start-up and inserted at shut-down. During an emergency shut-down or "scram" the rods are simply dropped into the reactor. As shim rods they can be used to give steady-state control to compensate for long-term effects such as fuel burn-up, and fission-product accumulation and to compensate neutron absorbing experiments.

The control, or regulating, rod has a much narrower control range and is moved in and out of the reactor in small steps. There is usually only one control rod and it is desirable, but not essential, to "scram" the control rod also during emergency shut-down.

Besides driving the rods up and down and "scramming," the control mechanism must recover the rods after "scram" so that start-up is once again possible. In reactors which operate at high neutron flux densities, the speed at which the rods are recovered may be critical. Build-up of xenon-135—a neutron absorber that "poisons" the reactor—after shut down, requires quick start-up; otherwise there must be a long wait for the xenon to decay.



Flexibility in choice of control system is offered by unitized character of components in reactor control mechanism. Fig. 1

Rod position must be known at all times. The control mechanism must relay the position signal to the console. For automatic control of the rods a velocity signal may also be necessary. Other signals relating to rod position are desirable, such as full-out stop and full-in stop.

To satisfy these individual requirements AMF has designed independent units. As a result, a mechanism can now be built to satisfy a specific set of conditions simply by the selection of appropriate units. The units have been broken down by an additional step to provide choices of life, accuracy, and cost. Figure 1 shows a mechanism, made of small units, which can satisfy all requirements of both safety-shim rod and control rod operation through the use of a rack-and-pinion drive to the rods.

A standard fractional-horsepower motor is adequate for the safety-shim rod because of the low speed involved, while a low-inertia motor is used for the much faster control rod drive.

A single-thread-worm reducer unit accepts both the servomotor and, with an adapter, the standard motor.

The next unit is a magnetic clutch and its housing. For emergency shut-down conditions the clutch disconnects the output shaft from the worm reducer and the rods, with racks attached, drop into the reactor under the influence of gravity. The clutch has a release time between 30 and 50 milliseconds. With this method of "scram" a mechanical latch holds the rod to the rack. Another method of "scram" inserts an electromagnetic coupling between the rod and rack, instead of the clutch. When the magnet is deenergized, (approximately 40 millisecond release time), the rod falls. This method is probably the simplest, but the clutch offers certain advantages. As mentioned before, rapid recovery of the rods may be very important. With the clutch-type "scram," the rod has never been released from the rack and pinion. Start-up requires merely energizing the clutch. With the magnet "scram," the racks must be driven down to recover the rods. Position indication is lost until contact is made again, while indication is never lost with the clutch system.

The drive shaft unit is a cylindrical casting with a boss for mounting the position pick-offs, the drive shaft and bearings, and the pinion. Gearing for the position pick-offs is taken directly from the output shaft. The position gearing makes one turn for the full rod travel, which in the case illustrated is 24 in. (The length of rod travel can be adjusted by limit switches). Interchangeable mountings are provided for a one-turn synchro or a one-turn or ten-turn helipot. Ratios are compensated by gearing built in the synchro or helipot base.

When using the magnetic clutch,

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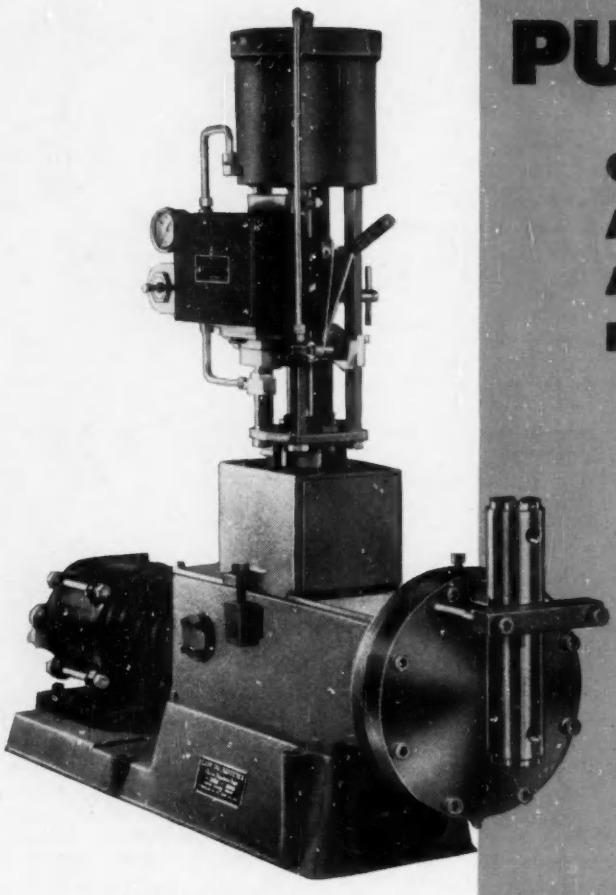


TWO PUMPS IN ONE!

Lapp Pulsafeeder is the combination piston-diaphragm pump for controlled-volume pumping of fluids. Reciprocating piston action provides positive displacement. But the piston pumps only an hydraulic medium, working against a diaphragm. A floating, balanced partition, the diaphragm isolates chemical being pumped from working pump parts—eliminates need for stuffing box or running seal. Constant pumping speed; variable flow results from variation in piston-stroke length —controlled by hand-wheel, or, in Auto-Pneumatic models, by instrument air pressure responding to any instrument-measurable processing variable.

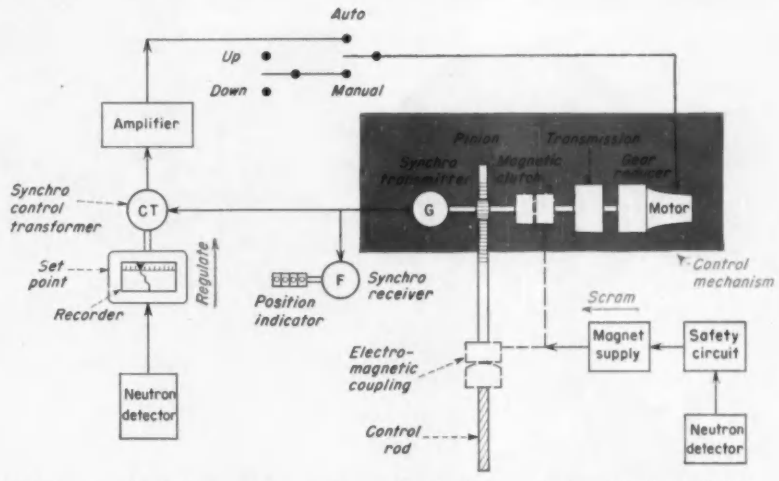
WRITE FOR BULLETIN 300 with typical applications, flow charts, description and specifications of models of various capacities and constructions. Inquiry Data Sheet included from which we can make specific engineering recommendation for your processing requirement. Write Lapp Insulator Co., Inc., Process Equipment Div., 390 Wilson St., Le Roy, N.Y.

the drive-shaft unit may also include a torsion spring to accelerate the rod at "scram."

The last unit is the rack back-up casting with attached guide housing. The rack rides in a linear bearing which holds proper pitch-line distances between rack and pinion. A bank of five limit switches is mounted to the guide housing, and can give any number of signals relating to rod position. A cam traveling with the rack actuates the switches.

The rack is just over 30 in. long and connects to an extension tube through a ball joint to allow for misalignment without cocking the rack in its bearing.

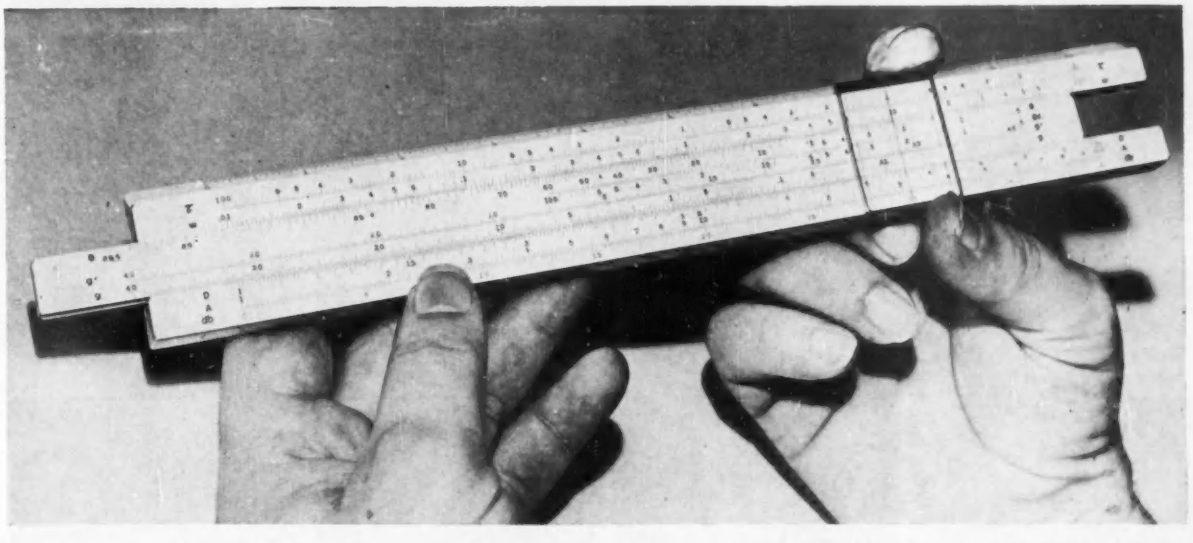
This unitized control mechanism can be used with almost any mode of control. A schematic of one typical system is shown in Figure 2. This shows the servo loop for the control rod. The safety-shim rods might have a slow-acting on-off control system operating to restore the control rod to the center of its operating range.



Typical research reactor regulating system using unitized control mechanisms. Safety-shim rod would use manual control with position indication only. Fig. 2

The mechanism described will drive 100-lb rods at specified speeds, allow them to "scram," recover them, indicate their positions, and provide position-sensitive signals to meet specific requirements. The unitized components are reliable. Standardization has reduced their cost.

FREQUENCY RESPONSE MADE EASY . . .



Any control engineer would like a slide rule which gives magnitude ratio and phase response angle in one setting. Yes, there is such a slide rule. It was recently invented by Keisuke Izawa, Assistant Professor at the Tokyo Institute of Technology. The rule is made by the Hemmi Bamboo Slide Rule Manufacturing Co. in Japan. [Your editors have been unable, to date, to locate an American distributor.]

A paper by Mr. Izawa, entitled "Frequency Response Calculation Aids," and to be published shortly by the ASME, describes the slide rule and its use. Two monograms make possible at-a-glance conversion from open- to closed-loop response values for both magnitude ratios and response angles, on the basis of unity feedback.

Specifically, the rule solves expressions which are factorable into terms of the form $Ts + 1$, s, e^{Ls}, e^{-Ls}, and Ks^h; where T and L are positive constants, $s = j\omega$, and $j = \sqrt{-1}$. The general transfer function of this type can be represented by $G(s)$,

$$G(s) = Ks^h \frac{(T_{a1}s + 1) \ldots (T_{an}s + 1)}{(T_{b2}s + 1) \ldots (T_{bm}s + 1)} e^{-Ls}$$

and K is the gain constant, h is the number of differentiations or integrations, the quantities T_{a1}, T_{a2}, . . . T_{an}, are lead time constants, while T_{b1}, T_{b2}, . . . T_{bm}, are lag time constants, and L is the dead time of the system. Given the various constants, the slide rule produces the magnitude ratio in decibels and the phase angle in degrees for any angular frequency between 0.001 and 1,000 radians per unit time.

Scales for direct conversion from decibels to actual magnitude, and from angular frequency to frequency (cycles per unit time) or period (time per cycle), are also provided. The new rule also has the standard C, CI, D, and A scales for multiplication, division, squares and square roots. Any ratio, as a number on the A scale, may be converted directly to decibles by reading the number opposite on the db scale.

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SPECIFICATIONS

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D1	20/second	10 counts	by hand
D1-12	20/second	12 counts	by hand
D2	200/second	100 counts	by hand
D2-144	200/second	144 counts	by hand
D5	5000/second	1000 counts	by hand
P2	60/second	number set	automatic
P3	60/second	number set	except
P4	60/second	number set	register
PW2	60/second	number set on upper control	automatic
PW3	60/second	knobs (worms on lower controls)	except
PW4	60/second	number set on	register

NOTE: The last category also adaptable as lineal footage counters. Currently in development stages is a new type of electronic relay which will only contain one tube, but will permit slow range counts up to 2 per second. The totalizer will register on direct impulse as the counts pass through the photo head.

Reliability in all kinds of counting operations . . . The Post Decitron eliminates costly production oversights and allows a continuous check of product total.

Available models cover every counting need from slow speed direct counting — to amazing totals of 6000 units per second.

Preset counters permit desired total counts i.e. dozens, fifties, gross lots, etc. Warning systems can be energized by special preset models to slow down or stop machinery, sound buzzers and perform a variety of helpful functions. Lineal footage counters measure production of paper, cloth etc.

You can save production losses with compact, inexpensive, Decitron electronic counters.

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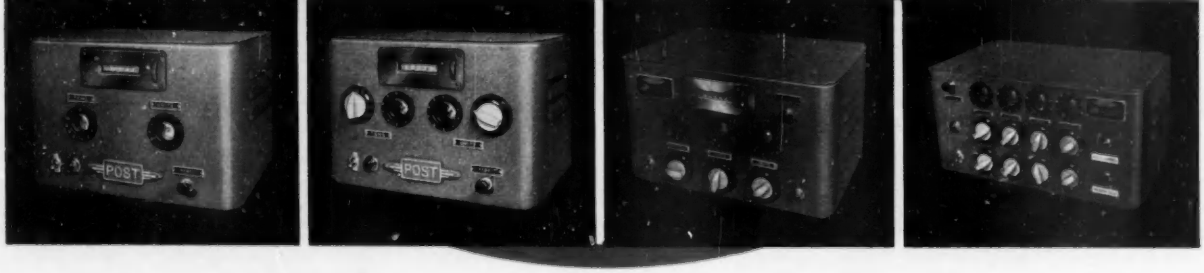
Double Decitron with 12 place tubes. Counts gross lots

MODEL P2
Counts in any desired total 1-100
Other models 1-1,000,000

MODEL P3
Preset counting any number 1-1000 inclusive

MODEL PW4
Desired count from 1-10,000 plus wired to warning system



POST

ELECTRONIC PRODUCTS DIVISION
POST MACHINERY COMPANY
Beverly, Massachusetts

Spectrometer Prints Analysis

R. L. HUDSON, Ethyl Corp., and
K. W. HERING, The Perkin-Elmer Corp.

Servo and digital techniques added to a basic laboratory spectrometer have reduced a complex chemical analysis to simple push button routine. Further, inherent precision in the new automatic system offers accuracy almost double that of good manual operation.

Specifically, the mechanized analyzer was developed to run a quantitative analysis of as many as ten components in a single chemical complex. Its basic instrument consists of a standard Perkin-Elmer Model 12 single beam spectrometer augmented by a control unit which sequences it through the ten predetermined wavelengths. At each point, first I_o then I are automatically measured by a cell-in, cell-out procedure. An analog to digital converter produces absorbency values in raw numerical form and feeds them to an electronic readout typewriter with associated punch equipment. Next the information goes to a digital computer which solves the simultaneous equations necessary for complete quantitative analysis.

Previously this whole procedure took place on a step-by-step basis. I_o and I readings were taken from a strip chart, and it was necessary to reduce these to a form that would permit calculations using the inversematrix. Since an electronic digital computer was a new acquisition at the Ethyl Corp. plant, it was believed that digitalizing would be an excellent way to accomplish these steps and also handle the problem of computing results.

Mechanizing the Instrument

Modifying the instrument consisted primarily in adding potentiometer follow-up servo drives for its slit and wavelength drums. A cell changer mechanism was first installed to permit alternate insertion of two cell holders into the optical beam.

Twenty 15-turn helical potentiometers are used to secure ten wavelength and slit openings. Ten of these "pots" on a panel select desired wavelengths between 2 and 15 microns.

A repeat cycle timer automatically sequences any number of wavelength settings and slit widths up to ten. Also, three additional wavelengths and slit widths are selectable by push button after automatic cycling is complete. These make possible rapid wavelength calibration and zero checks of the instrument.

The program control, in addition to power supply and control relays, contains a one-minute repeat cycle timer. Five microswitches, coupled to this timer, achieve the following sequence:

1. Wavelength and slit selector point advance.
2. Recycle.
3. Cell in-cell out.
4. Recorder chart-pen "on" and "off".
5. Readout.

Performing readout are a Telecomputer Corporation "Teleducer", a program unit, and an IBM typewriter. The "Teleducer" is a self-balancing Kevin-Varley bridge which measures voltage from an auxiliary slide wire coupled to the recorder pen.

Functionally, the program unit picks off information from the "Teleducer" and programs this into the modified IBM typewriter. Readout code number and up to twelve selected constants are also fed into the typewriter.

As an added convenience to the operator, a remote push button panel is on the spectrometer table. Control here consists of cell "in"-"out", chart "on"-"off", the three calibration points, standby, automatic analysis start, reset, and manual readout.

Operational Sequence

To set up the instrument for a quantitative analysis the wavelengths and slit widths are preselected on the potentiometers—these settings being made by visual observation of wavelength drum and slit width scale positions. Only one zero setting is used for all wavelengths. This is permissible as long as proper precautions are taken for nonlinearity due to scattered light or overly wide spectral slits.

In operation the recycle switch selector is set for a desired number of points. Zero is then checked using the above calibration point and manually introducing the fithium fluoride shutter. This check is necessary only once every four or five samples. After zero has been set the instrument is returned to standby and sample is introduced. The operator then pushes the start button which initiates the following sequences:

1. The cell travels to the "cell out" position and stays there for 30 seconds.
2. The wavelength drum and slits are servoed to position 1 and remain there for 60 seconds.

"Up a Tree" with a Relay Tree?...

Here's Your Answer!

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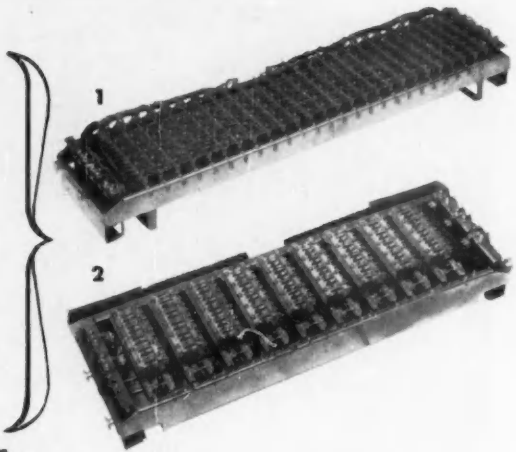
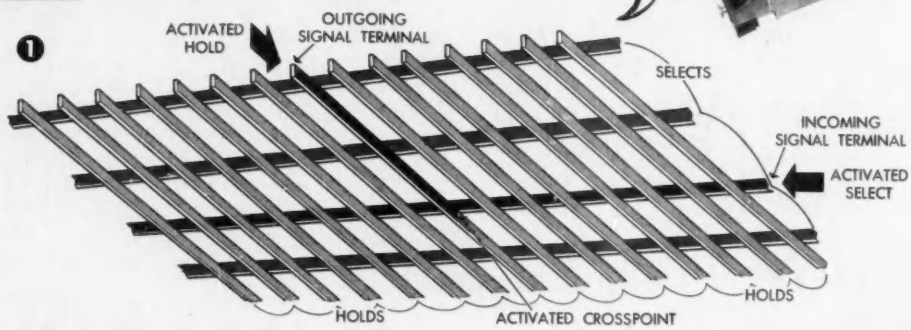
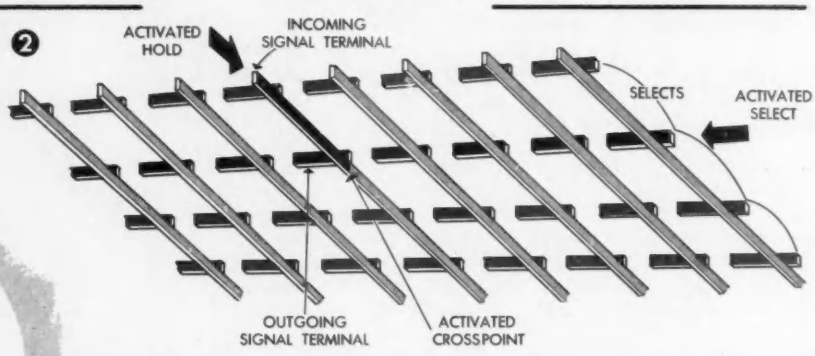
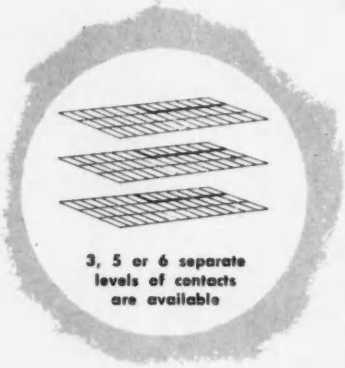
Fast, Simple, Low-Cost Solution to Your Complex Switching Problems!









3, 5 or 6 separate levels of contacts are available

The Kellogg *Cossbar Switch* illustrated above establishes the different types of electrical connections possible. Any cross point can be activated in less than 50 milliseconds by energizing one select magnet and one hold magnet. Standard contact material used in the Kellogg *Crossbar Switch* is palladium (gold can also be provided). Mounting frames are available which provide drawer-like removal for easy inspection. Circuits can be maintained while the Kellogg *Crossbar Switch* is in the process of switching other circuits.

1 **Drawing No. 1 illustrates the basic Cross-bar principle which permits any of several incoming circuits to be connected to any of several output circuits. This type of switch can connect any of 60 circuits, 3 at a time, to any of 75.**

2 **Drawing No. 2 shows a means of switching one incoming circuit to many possible outgoing circuits—accomplished by removing every other vertical. Thus, instead of having one cable terminal at one end of the switch, each remaining vertical has its own cable connection. This type of switch can easily be adapted to switch one circuit to any of 936.**

Write for Technical Bulletin Today! Dept. 72-I

KELLOGG — DIVISION OF I T&T

KELLOGG SWITCHBOARD AND SUPPLY COMPANY

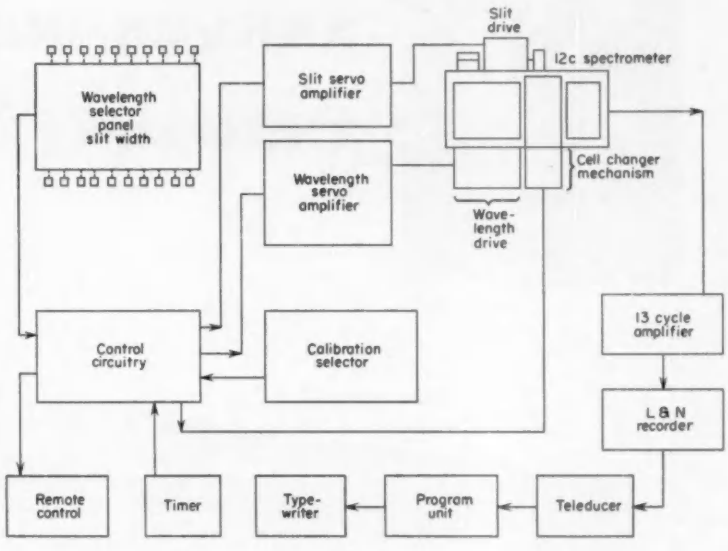
A Division of International Telephone and Telegraph Corporation

Sales Offices: 79 W. Monroe Street, Chicago 3, Illinois

3. After 15 seconds from start of above the pen motor of the recorder is activated.
4. After 28½ seconds a readout is taken. This reading is the transmittance value (I_o) with the cell out of the optical path.
5. The pen motor is de-energized after 30 seconds at which time the cell travels to "cell in".
6. After 45 seconds the pen motor is again energized.
7. A readout for the cell in position (transmittance value I) is taken after 58½ seconds.
8. The pen motor is deenergized.
9. After 60 seconds the wavelength drum and slits are servoed to position 2 and cycle repeated.

Analytical results to date indicate a standard deviation of less than ±.001 absorbancy units in the 60 to 35 percent transmission range, and ±.002 units in the 35 to 15 percent range.

MULTICOMPONENT ANALYZER BLOCK DIAGRAM



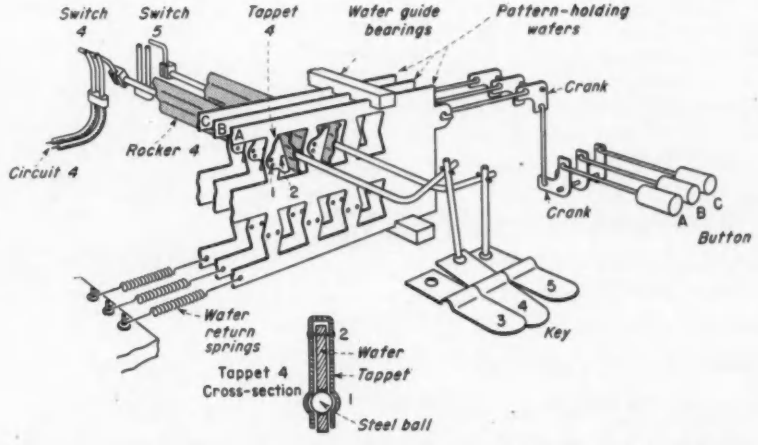
Push-Button Mechanical Memory

EUGENE R. KILGEN, Kilgen Organ Co.

A memory device should be easy to fill, and just as easy to empty. Its capacity—the number of pieces or bits in the pattern—should be easy to enlarge. It should be compact and must be reliable. This push-button memory meets all these requirements.

The drawing has been simplified to include only two switches and three of the pattern-remembering wafers. The switches are mounted at the end of rockers and are operated by the tablet-type keys marked 3, 4, and 5. The pattern-holding wafers operate all switches simultaneously; each switch, by way of its rocker, assuming the position of the corresponding tappet on the wafer selected.

Each tappet has two positions, since a switch can be simply on or off. The tappet is pivoted at point 2 (see tappet 4 on drawing) and has a friction device (see insert) which biases the tappet in one position or the other.



Each of the wafers holds a pattern in the positions of its tappets, and this pattern is transferred to the switches by pressing the corresponding button. There may be hundreds of switches and hundreds of buttons.

Normally, the tappets operate the rockers. A pattern is set, however, by using the rockers to set the tappets, and a pattern is removed in the same way. Depressing button A moves the tappets of wafer A against the rockers, setting the pattern of those tappets into the switches. The button is then released, and the wafer returns to its rest position, leaving the switches as set. If the button is held, however, the keys can be used to set the tappets, removing or changing the pattern on the wafer concerned. A wafer may operate a great number of switches, and, since the wafer has a rest position, one or two switches may be opened or closed, varying the pattern in a small way, without affecting the basic pattern.

The mechanism has been successfully built with 350 switches and 50 wafers. The switches can be cam-operated microswitches. The keys and buttons can be replaced by solenoids or clutched to a motor.

A device of this kind could be used in place of the patch panel in setting up problems on analog and digital computers, especially large ones. It has controlled airport traffic-pattern lights. Modifications of the mechanism might be useful in this respect; a means, for example, to disconnect the switches from the keys, so a pattern may be set into another of the wafers without disturbing the switches.

GPE SERVES INDUSTRY THROUGH *coordinated*

The producing companies of General Precision Equipment Corporation are engaged in the development, production and sale of advanced technological products. These products all have a broad common base: 1) they represent precision equipment in some form; 2) they derive from similar fields of technical competence; 3) they save labor, increase productivity, or achieve results which cannot be attained with even limited use of on-the-spot manpower.

A general view of the technical capacities of the GPE Producing Companies is given in the chart. But the chart cannot show the very close interrelation of these capacities nor the highly flexible application of facilities, techniques and capabilities which exists among these companies. This is achieved through GPE's basic operating policy—Coordinated Precision Technology.

GPE Coordinated Precision Technology operates in all areas—in research, development and manufacture. The record of the GPE Producing Companies in solving advanced technological problems and meeting the demand for high speed, precision, reliability, light weight and compactness at competitive prices is the result of this coordination, the constant application of the newest and most highly advanced techniques, and unremitting insistence on highest quality.

Perhaps the most conspicuous advantage of GPE Coordinated Precision Technology is that the concept and development of equipment and systems, and of solutions to the underlying technical problems, are not restricted by being confined to the specialized techniques of a particular field. In short, GPE Coordinated Precision Technology permits each company to seek the optimum solution for the customer by the application of all relevant techniques within the total capacities of the entire group. Address inquiries to:

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92 GOLD STREET, NEW YORK 38, NEW YORK

Over **2200** scientists, engineers, draftsmen, testers and other technical personnel in the GPE Companies work in the fields covered by this chart.

CAPACITIES OF THE GPE PRODUCING COMPANIES

- PRECISION MECHANICS and CERAMICS
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- ELECTRONICS
- HYDRAULICS and LIQUIDS HANDLING
- PROFESSIONAL and INDUSTRIAL TELEVISION EQUIPMENT
- INSTRUMENTATION
- SERVOS and CONTROLS
- AUTOMATIC COMPUTERS and COMPONENTS
- ULTRASONICS
- RADAR and MICROWAVE
- MOTION PICTURE and SOUND EQUIPMENT
- OPTICAL DEVICES

THE GPE PRODUCING COMPANIES

Simplex — INTERNATIONAL PROJECTOR CORPORATION—BLOOMFIELD, N. J.

Peerless — J. E. McAULEY MFG. CO. CHICAGO

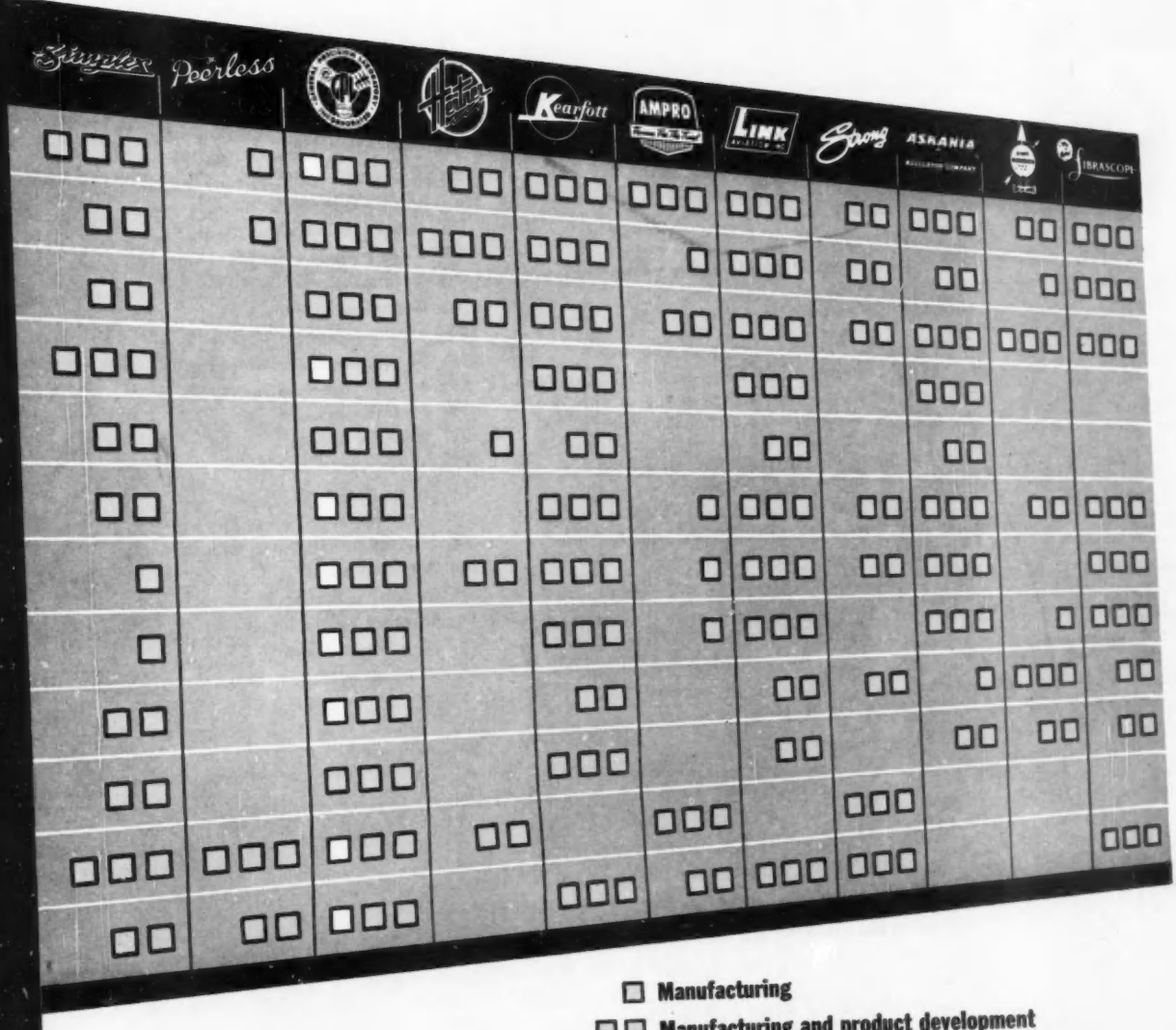
GPL — GENERAL PRECISION LABORATORY INCORPORATED—PLEASANTVILLE, N. Y.

Hertner — THE HERTNER ELECTRIC COMPANY—CLEVELAND

Kearfott — KEARFOTT COMPANY, INC. LITTLE FALLS, N. J.

One of a series telling
how the producing companies of
General Precision Equipment Corporation
are contributing to America's progress.

precision technology



□ Manufacturing

□□ Manufacturing and product development

□□□ Manufacturing, product development and research

□□□ Pilot manufacturing, product development and research

AMPRO CORPORATION
CHICAGO

LINK AVIATION, INC.
BINGHAMTON, N. Y.

THE STRONG ELECTRIC
CORPORATION—TOLEDO

ASKANIA REGULATOR
COMPANY—CHICAGO

GLUDWORTH MARINE
NEW YORK

LIBRASCOPE, INCORPORATED
GLENDALE, CALIFORNIA

New Products

AUTOMATIC INSPECTOR circuit-identifies wires in large cables and spots flaws.

With this cable scanner operator can circuit-identify a 100-conductor cable at the rate of .03 seconds per wire—a manual job which normally requires at least 5 seconds per conductor. Further, the device will automatically check resistance at a rate of one wire per second.

Functionally the cable scanner is divided into master and slave units. In the master are all operating controls and adjustments necessary to inspection function. Sole duty of the slave is in cable identification routine. Both units are portable and use 115V-60 cycle power. Conductors for test—up to 12 gage—can be quickly connected by spring lock binding posts.

For identifying individual wires in a cable, ends are connected to both master and slave. The master then runs its end through a sequence which permits identification in both units by a coordinate light system. As each identified wire is tagged by the operator, the master advances and stops.

In scanning cable for interconductor and ground resistance, only the master unit is involved. Here, a DC bridge circuit, using vacuum tubes and relays as sensing devices, detects any faults. Acceptance limits are adjustable between 10 and 100 megohms at 350 VDC. When a fault shows up the scanner stops, identifying lights tab the conductor, and the wire number is logged.

Primary function of the new device is in quality control of simple or complex electrical cables. It should be excellent for inspecting the maze of electrical wiring in prefabricated harnesses for guided missiles, aircraft, and automatic fire control systems. Also in routine trouble shooting in involved networks serving computers. *Panascan, 7461 N. Hamlin Ave., Skokie, Ill.*

(Circle **No. 1** on reply card)

DIGITAL CONVERTERS with input-output versatility.

This series of compact, low-cost, remarkably versatile digital converters has been developed by the newly organized Data Reduction and Automation Division of Fischer & Porter Co. These units are designed to handle a wide variety of mechanical or electrical inputs and translate them into decimal or binary code necessary for readout or computer operation.

LISTING

1. Automatic inspector
2. Digital converters
3. Fluctuating-pressure transducer
4. Absolute-pressure transducer
5. Pressure-to-frequency transducer
6. Potentiometer-type pressure transducer
7. Temperature-monitoring system
8. Miniature magnetic clutches
9. Oscilloscope with four-gun tube
10. Infra-red photocell
11. Electronic counter
12. AC bridge controller
13. Portable potentiometer
14. Btu computer
15. Vibration monitor
16. Precision spectrophotometer
17. Tension analyzer
18. Nylon resin
19. Subminiature toggles
20. Ultrasonic thickness gage
21. Program control system
22. Linear differential transformers
23. Minute servo components
24. Plug-in pulse transformer kit
25. Decade tube
26. Generater
27. Miniature speed reducer
28. DC tachometer generators
29. 40-volt selenium rectifier
30. Crystal photocell
31. Solenoid valves
32. Power digitalizer
33. Small diameter bellows
34. Magnetic servo amplifier
35. Magnetic fluid transmission
36. Precision cams
37. Remote indicators
38. Resolver amplifier
39. Push-button timer
40. Holding coil

Illustrated here is a typical member of this new series. It has a pit-coded two-drum train. When an analog signal rotates the drum drive shaft, mechanical contact "feelers" pick up drum position through its coding. Combination of these contact signals represents the output code—or drum position in digital form.

Two basic types of converter are available. One, which handles analog input voltage, contains an integral self-balancing potentiometer and will operate on a 0-1 millivolt signal and up. It is able to maintain either a linear or non-linear relationship between input and output signals.

The other basic type converts mechanical motion into digital signal output. Motion can be delivered to its input shaft by direct link or through

a pneumatic or other receiving mechanism. The torque requirements of this type of converter are less than 0.20 inch-ounce.

Both converter types are able to deliver equal variety in output signal. For example, they can produce the decimal code required to actuate most electric typewriters and IBM equipment—or the binary code which is diet for many computers. Further, it is claimed that this is the only converter able to come up with special output codes such as teletype and binary-decimal.

The maker of this new converter series believes its product is substantially less expensive than others of equal performance. This is apparently due to its purely mechanical conversion through simple coded drums, rather than via complex electronic circuitry or costly components. As many as ten such coded drums can comprise a train in the device.

Remarkable precision is available in this simple drum-to-feeler conversion. Feeler positioning has been found positive, even though the final drum in a train may move one ten-billionth of a revolution. This results, for example, in an output accuracy in a five-drum train of better than one in 34 billion parts.

In operation, motion of the input shaft in the first drum is passed on through the train by a series of reduction gears. Optional use of a hysteresis free input coupler will permit feelers to operate without interrupting the motion of the input shaft. Operational speeds can be as high as 5,000 counts per second.

Applications for analog to digital converters of this type exist wherever it is desirable to change the output from a primary measuring device into a direct digital signal. Thus it should find much function in converting variable measurements, such as flow, pressure, chemical composition, into a highly useable form for information, computing and feedback control. *Fischer & Porter Co., Hatboro, Pa.*

(Circle **No. 2** on reply card)

FROM THE WEST COAST this month comes a remarkable variety of new pressure transducers. Reflecting the aircraft industry's preoccupation with miniaturization, all are notably compact. Four of the most exciting are listed below.

FLUCTUATING PRESSURE:

Threading for flush mounting plus protruding reference-pressure and electrical connections make this miniature bonded strain-gage transducer easy to handle and apply.

Actually, prototypes of these tiny 4.5-gram sensing devices have been used since 1946 in special applications involving fluctuating pressures. Their direct contact between sensing diaphragm and pressure source, as well as structural simplicity, is said to eliminate phase and amplitude errors normal to many pressure measuring arrangements.

Inside the unit, a 120-ohm strain gage is bonded to the inner surface of the contact diaphragm and wired to electrical terminals. Hence, in measurement, the device serves as active arm of a 120-ohm bridge circuit.

The transducer is $\frac{1}{2}$ in. in diameter and $\frac{1}{4}$ or $\frac{3}{8}$ in. in length. It is available in seven pressure ranges—from $2\frac{1}{2}$ to 200 psi—and will operate in a range from −40 to 250 deg. F. Claimed linearity is 2 per cent, and acceleration effect 0.02 per cent per G. *Electronic Engineering Associates, Ltd., 948 Brittan Ave., San Carlos, Cal.*

(Circle **No. 3** on reply card)

ABSOLUTE PRESSURE:

An evacuated aneroid-type bellows in this compact 7 oz, $2\frac{3}{4}$ in. long transducer sets it up for rugged absolute pressure measurements in such ranges as 0-2; 0-4; 0-20; 3-14.7 psia. Construction and rangeability appear ideal for high altitude work as well as for many process applications involving vacuum.

A pre-exercised and calibrated beryllium copper diaphragm-type bellows gives optimum linearity and minimum hysteresis. Electrical analogy is provided by a contact arm with counterbalanced linkage, that pivots in a miniature ball bearing assembly. The electrical output of $\frac{1}{2}$ watt needs no amplification and may be fed directly into telemetering or recording and control systems.

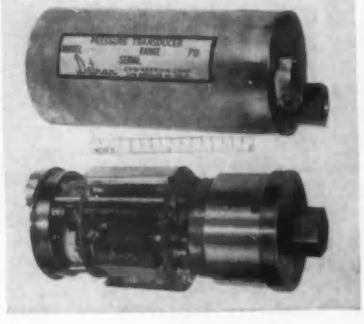
Outstanding resolution characteristics of 0.25 to 0.50 per cent are claimed for resistances of from 1,000 to 10,000 ohms.

Known as Model 408 Absolute Pressure Potentiometer, the new transducer is power rated at $\frac{1}{2}$ watt at 160 deg. F. and comes with standard resistance values of from 1,000 to 10,000 ohms. *Bourns Laboratories, 6135 Magnolia Ave., Riverside, Cal.*

(Circle **No. 4** on reply card)

PRESSURE TO FREQUENCY:

Designed primarily for use with standard RDB FM/FM telemetering systems, this pressure-to-frequency transducer appears to have interesting possibilities for such industrial applications as liquid level measurement and storage tank monitoring. As a differential gage, its manufacturer claims, it will display unusual precision and reliability in remote pipe line measurements of flow.



Only 3⅛ in. long and 1¼ in. in diameter, the new transducer has a variable inductance pressure pickup mounted in the same case with an FM oscillator. It is available in pressure ranges from 3 to 100 psi. Weight of the device is 6½ ounces.

In operation, applied pressure is converted to proportional frequency within the transducer and supplied at constant amplitude across its output terminals. It produces output center frequencies of from 1 to 80 kcps.

High stability is claimed for this unit. Sensitivity change with temperature is indicated as less than 0.02 per cent per degree F., and zero drift no more than 0.02 per cent of bandwidth per degree F. in the −6-deg.-to-200-deg. range. *Datran Engineering Corp., 6312 W. 92nd St., Los Angeles, Cal.*

(Circle **No. 5** on reply card)

POTENTIOMETER TYPE:

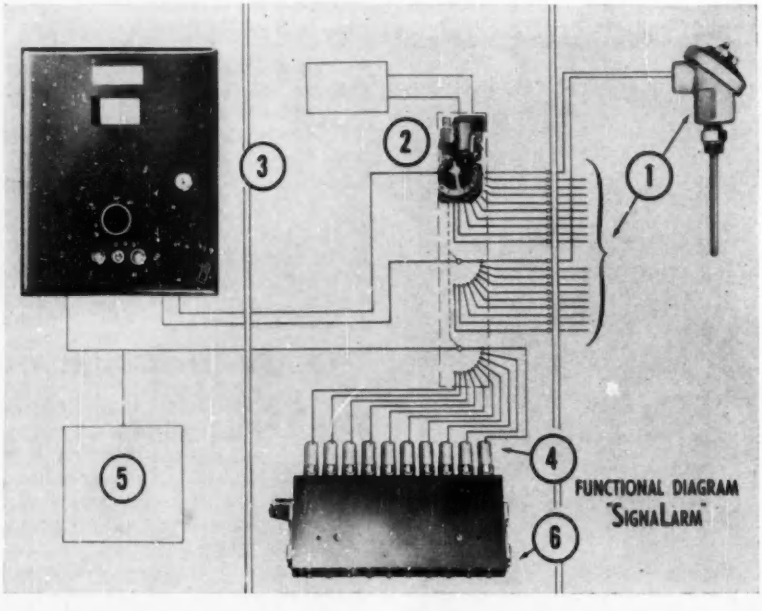
This compact pressure transducer has potentiometer-type transmission, the "pot" being isolated by bellows from actuating force. Although primarily designed as an absolute pressure device, it is also offered in gage and differential pressure for measuring both atmospheric and fluid pressure.

In operation, a pressure-sensitive bellows in the unit moves brushes over one or two precision potentiometers.

Some facts and figures on specifications: 2½ in. long and 2 in. diameter; weight is 8 oz.; operating range is from minus 50 to 90 deg. C.; current rated at 7.0 milliamps; has a static friction maximum of 0.5 per cent of full scale; linearity is 1.0 per cent of full scale; resolution is 0.34 per cent of full scale in standard models; the unit is designed for 50 per cent overpressure.

This product underwent severe testing before its marketing. It was found to withstand over 40 G shock on any axis and was undamaged by 10 G vibration from 10 to 500 cps. It also held up at 40 G steady-state acceleration. *Genisco, Inc., 2233 Federal Ave., Los Angeles, Cal.*

(Circle **No. 6** on reply card)



TEMPERATURE MONITORING SYSTEM employs standardized units, and is easy to expand.

Basic components in this temperature scanning system include:

- Thermocouples (or resistance bulbs)
- Impulse timer and stepping switch
- Master measuring unit
- Memory relay
- Audible alarm
- Signal lamps

All these components are standardized and pre-tested, with extra elements available for increasing capacity or scope of scanning.

In operation, the master measuring unit, with its servo-balancing bridge, is pre-set to give warning signals at a high or low temperature. When scanned temperatures are normal a green light flashes. When, however, an abnormal temperature is sensed, a red light goes on and buzzer sounds. A pushbutton will silence the audible alarm but the warning light will continue to shine until the faulty point is corrected. *Thermo Electric Co., Inc., Rochelle Park P. O., N. J.*

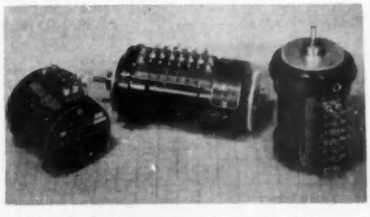
(Circle **No. 7** on reply card)

MINIATURE MAGNETIC CLUTCHES with fast response.

A new line of magnetic clutching and braking devices is available for computer and servomechanism applications requiring high accuracy. Included are: a single clutch, a double clutch, and a clutch brake.

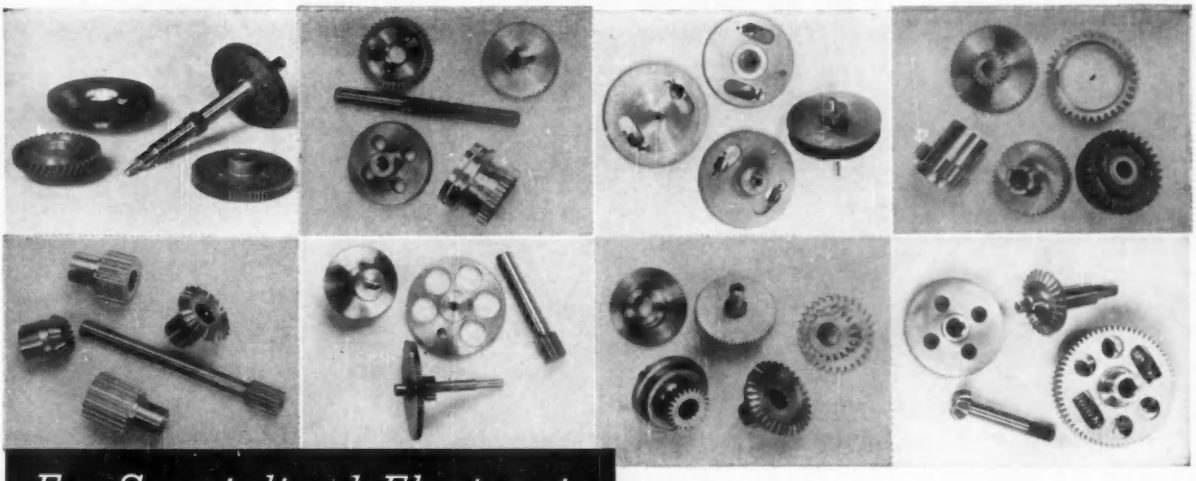
Designed to meet military environmental specifications, the units are made of corrosion-resistant and fungus-inert materials. Windings are encapsulated; finish is anodized. Characteristics:

Minimum response time	—6 milliseconds
Maximum torque	—16 oz.-ins.
Moment of Inertia	
Input shaft	—0.30 oz.-in.²
Output shaft	—0.21 oz.-in.²
Life expectancy	—200,000 cycles at 30 rpm with 1 oz.-in.² load inertia
Temperature range	—minus 65°F to plus 165°F.
Weight	
Single clutch	—0.8 pound
Double clutch	—1.5 pounds
Clutch brake	—1.2 pounds
Supply	—25 vdc.



Ford Instrument Co., Division of the Sperry Corp., 31-10 Thomson Ave., Long Island City 1, N. Y.

(Circle **No. 8** on reply card)



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Mission-Western Engineers offer an unusually wide range of basic miniature motor designs. We have available more than fifty basic types, including axial and centrifugal blower designs to cover the great variety of equipment adaptations. Our basic motor designs range from .001 to 2 H.P., from 50 to 1,000 cycles in frequency and in any voltage range required. Complete motor design service available. For further information or a copy of our motor catalog #254, write Mission-Western Engineers, Inc.,* 132 West Colorado Street, Pasadena 1, California.

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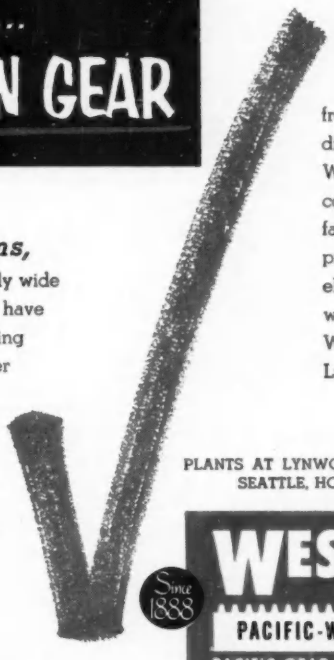

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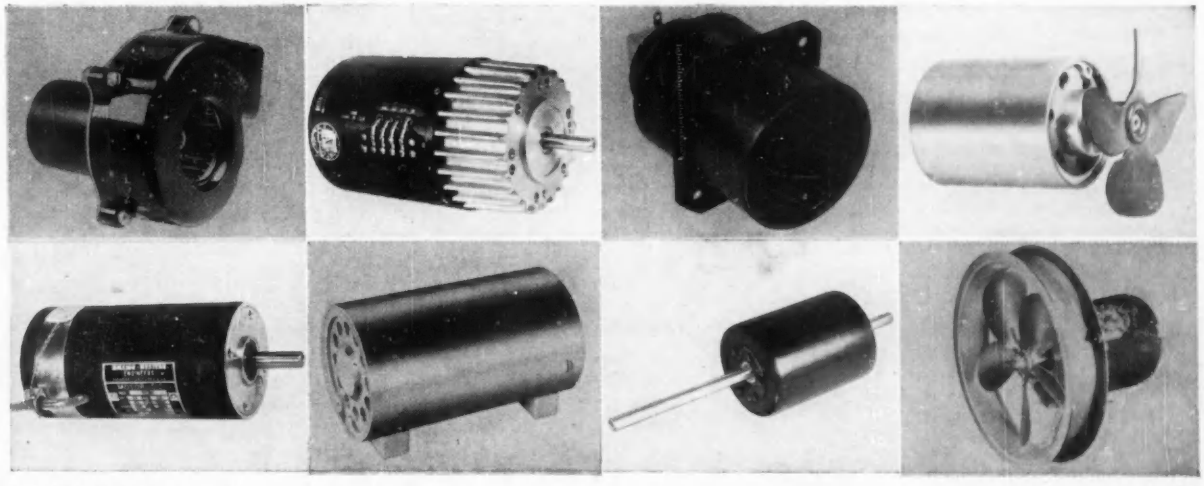

ANALOG COMPUTER and SIMULATION FACILITIES

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Now available for consultation and hire are competently-staffed independent organizations fully-equipped with EASE computers and linked in a network to provide full interchange of experience and operational techniques.

Users of any local facility thus receive two important benefits: (1) availability of complete EASE computation and simulation equipment of latest design, at all times; (2) most advanced techniques, and an ever-growing fund of experience, as developed by all network members.

You are cordially invited to visit and investigate the nearest organization having an EASE facility, (see list below) and to discuss your problems involving mathematical analysis, system simulation and other phases of research, design or development work in which modern analog computer techniques offer substantial savings in time and cost.

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Berkeley division Beckman Instruments Inc.
Chalmer Jones: LAndscape 6-7730

LOS ANGELES, CALIF.
Dynalysis, Incorporated
E. Noneman: ARizona 7-6786

BIRMINGHAM, ALA.
Southern Research Institute
A. J. Thomas, Jr.: 54-2491

ROSELAND, N. J. (New York City area)
Gawler-Knoop Co.
Allyn W. Janes: DIgby 4-8417

CHICAGO, DETROIT, BATON ROUGE, MONTREAL—facilities open soon.

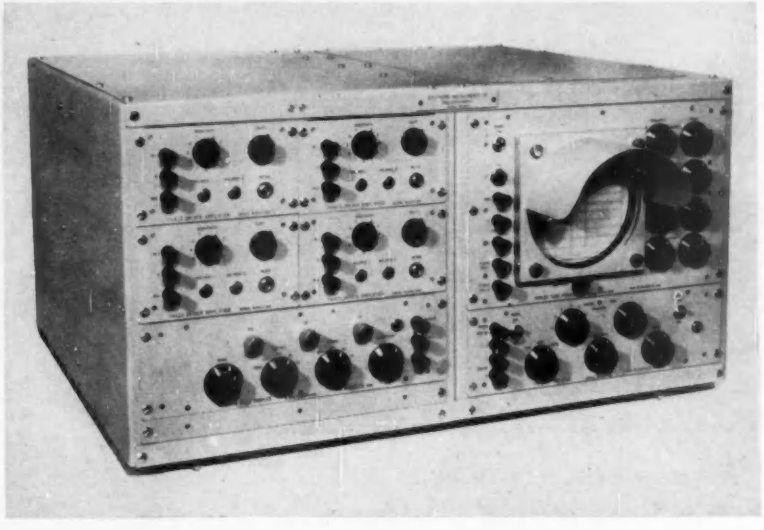
Computer application bulletins available on request... please address Dept. L9

M-38

Berkeley *division* BECKMAN INSTRUMENTS INC.

2200 WRIGHT AVENUE, RICHMOND, CALIF.

DEVELOPMENTS FROM BRITAIN. On display at the British Industries Fair last spring were several products of interest to control engineers. Here are four electronic items. Two are already available through American business representatives.



OSCILLOSCOPE WITH FOUR GUN TUBE:

Almost any four electrical or physical events below 100 kilocycles per second can be displayed visually or recorded photographically by this new cathode ray oscillograph. This flexibility suits the instrument particularly to complex developments which often demand detailed study of several simultaneous events.

Briefly, signals from four independent variables can be amplified and applied to the four-gun tube in this oscillograph. If the signals are voltages they can be applied directly to the instrument amplifier. If they are outputs from pressure or other transducers, specialized pre-amplifiers are needed to convert to waveforms which can then be applied to the tube.

The instrument's four-gun cathode-ray tube has a 160 mm diameter flat screen and an accelerating voltage of 1.9 kv. It employs four direct-coupled driver amplifiers, a time-base, and a time-marker oscillator. Time-base frequency range is one to 50,000 cps. Accuracy of the oscillator is 0.1 per cent and maximum output is 200 volts. *Southern Instruments, Ltd., Frimley Rd., Camberly, Surrey, Eng.*

(Circle **No. 9** on reply card)

INFRA-RED PHOTOCELL:

This newly announced photoconductive cell of the lead sulphide type is so responsive to heat radiation that it is said to pick up temperatures in moving work at a distance of 100 yards or more.

The new cell simply consists of a lead sulphide layer between two electrodes deposited on a glass base. Hence its rugged compact construction makes it highly suitable for use in radiation sensing heads as well as for direct mounting in previously unreachable industrial locations. Application possibilities include axle bearing monitoring, radio-frequency heating control, regulating fuel feed to furnaces—in fact, any job where actual contact with the work for temperature measurement is not permissible. *Mullard, Ltd., Shaftesbury Ave., London, W. C. 2. (American Agent: International Electronics Corp., 137 Hudson St., N.Y.C.*

(Circle **No. 10** on reply card)

FEEDBACK FACT:

Posed: Some means of graphically indicating water purity on panel controlling industrial waste process.

Solved: Foxboro ichthyologists came up with a flush-mounted gold fish bowl. Fish wiggles told more than pen wiggles.

SHEFFIELD

AUTOMATION Gages

Assure Fast Accurate Machining

Sheffield Automation Gages are package units, ready-to-use and economically priced, for the control of grinding, boring, drilling, honing, milling and turning operations.

Mounted on machine tools, they measure work part dimensions and space relationships and instantly translate this information into electrical impulses which in turn:

- **Energize signal lights**
- **Actuate solenoid ejection or classification mechanisms**
- **Start and stop the machine tool**
- **Provide feed-back control**
- **Control cutting tool or grinding wheel positioning and compensation, also time cycle.**

A Typical Application

Here the bore of transmission pinions is being honed and gaged automatically.

If the actual bore size, after honing, is within .0001" of either tolerance limit, white warning lights flash on.

If either tolerance is exceeded, a red or green signal flashes and the faulty part is automatically ejected.

When a predetermined number of rejects pass through in succession the machine is automatically stopped.

The actual size of each bore, as it is gaged can be read on a conveniently located air gage dial as built into the machine tool pneumatic circuit.

The Sheffield Corporation, Dayton 1, Ohio, U.S.A.

MASTER CRAFTSMAN SHEFFIELD HEADQUARTERS

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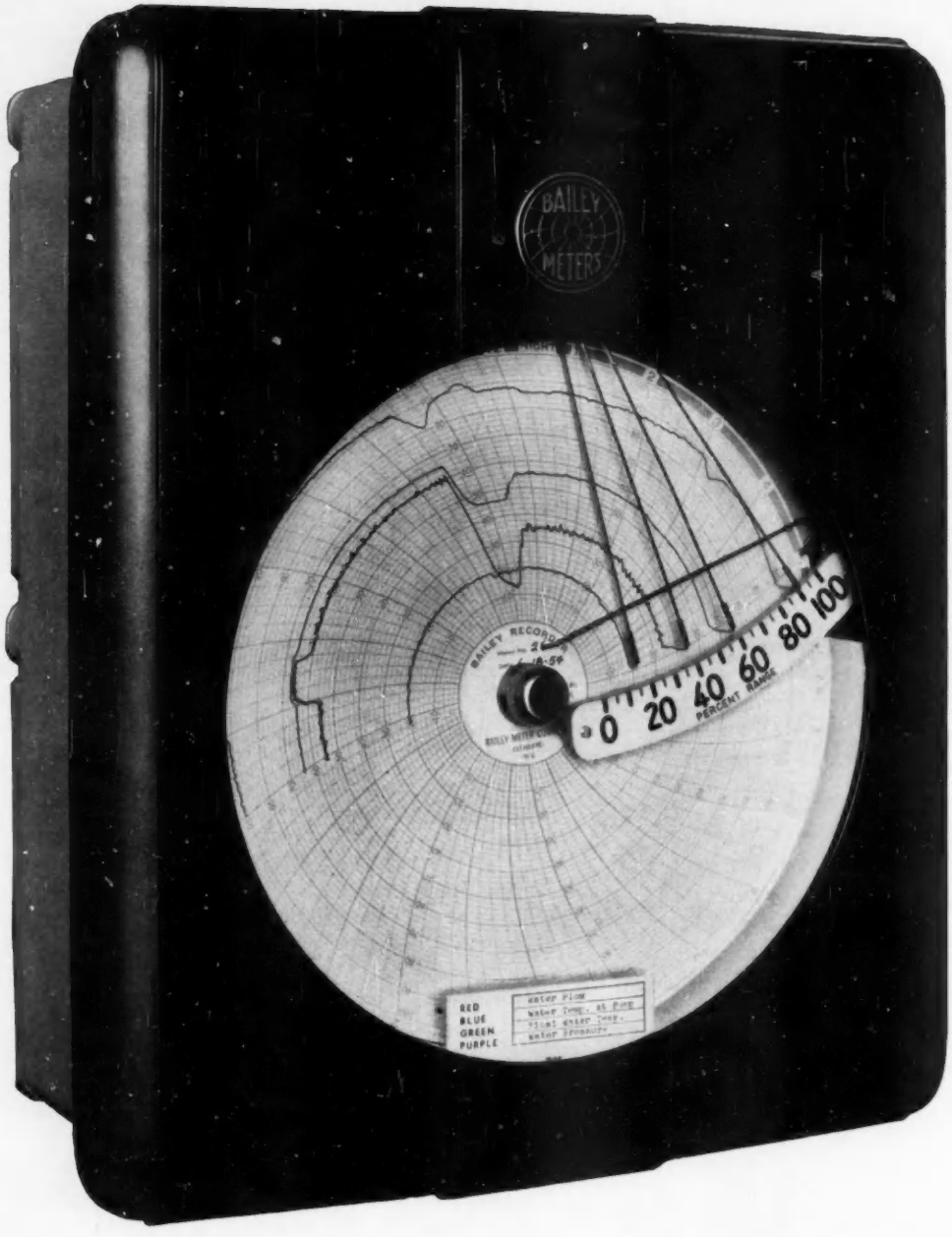
Sheffield AUTOMATION ENGINEERS will gladly consult with you about automatizing your production.

6891

Announcing the New Bailey

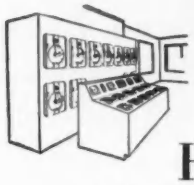


The New Bailey Recorder provides continuous chart records of any four measured variables:

% combustibles	density	flow	pH	ratio	speed
combustion	diffcrential	liquid level	position	smoke density	temperature
conductivity	draft	% oxygen	pressure	specific gravity	vacuum

Recorder for—

Pneumatic and Electric Transmission Systems



Here is a panel-mounted recorder that offers new versatility never before available in a single instrument. Its unique interchangeable-unit design permits recording up to four measured variables, regardless of their nature or the location at which they are measured.

Individual plug-in type pneumatic or electronic receivers—and corresponding integrators—are interchangeable in the four identical frame-slots, permitting any combination of four pneumatic or electronic signal receivers, *or any two receivers and their two integrators.*

For the first time you can record four telemetered measurements on a single 12-inch circular chart—with a minimum of first cost and installation expense, and a maximum of operating economy. Low cost multi-purpose components permit fast and easy adaptation to new or changed process cycles.

Visit the Bailey Booth at the Instrument Show
Check These Outstanding Advantages

Extreme Flexibility of Application is provided through the use of pre-calibrated plug-in type units—pneumatic or electronic—to record any measurable variables, in any combination. For example, you can "plug-in" pneumatic receivers along with electronic receivers to record up to a total of four variables on the same chart. Or your recorder casing can accommodate two integrators and their two corresponding recording receivers for rate of flow.

Faster, Easier Servicing of instruments is possible because of the new, sealed ink sacs and capillary pens. Under normal conditions ink sacs need be replaced only once each year. There is no day-to-day inking of pens.

Faster, Easier Ordering from Stock results from the unique standardized unit design. You can select any combination of recording receivers to fit your needs, by reference to simplified catalog specifications, and receive shipment without the delays ordinarily resulting from custom assembly. Complete interchangeability of plug-in type components simplifies stocking of spare units.

G34-2

Write for complete specifications—use handy coupon below

Plug-in type pneumatic receiver

Plug-in type integrator

Plug-in type electronic receiver

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LOW INERTIA SERVOMOTORS AND INTEGRALLY-MOUNTED TACHOMETERS

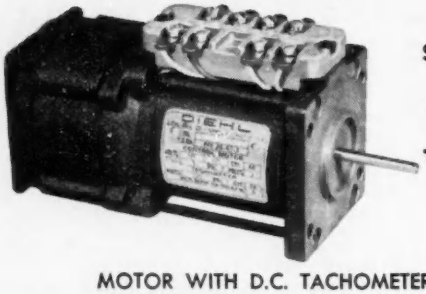
Response and stabilization of *Positioning Systems* can be improved with the Diehl Servomotor and *A.C. Tachometer*.

Analog System integration is facilitated by the use of the Diehl Servomotor with *D.C. Tachometer* combination.

Save space . . . and eliminate coupling problems and backlash . . . with these integrally combined units, motor and generator on the same shaft.

Diehl 5-watt output, 2-phase, 115/115 volt, 60 cycle, 2-pole Low Inertia Servomotors are available with a drag-cup type A.C. generator or with a permanent magnet D.C. generator mounted on the Servomotor as an integral unit, as illustrated:

MOTOR WITH A.C. TACHOMETER—NO. S.S. FPE25–67–1



Stalled torque: 5.0 oz. in.
Rotor moment of inertia: 0.18 oz. in.²
Tachometer output: 6 volts/1000 R.P.M.

MOTOR WITH D.C. TACHOMETER—NO. S.S. FPE25–86–1

Stalled torque: 5.0 oz. in.
Rotor moment of inertia: 0.18 oz. in.²
Tachometer output: 6.5 volts/1000 R.P.M.

These units are also obtainable for 10 watts output. Both the 5 and 10 watt units can be supplied with control windings for operation directly from the plates of vacuum tubes, or for 400 cycle operation.

Our engineering staff will gladly help you select the units best suited to your specific requirements. A request on your letterhead will bring you a copy of Technical Manual No. CT-0954 describing Diehl Servomotors and related equipment.

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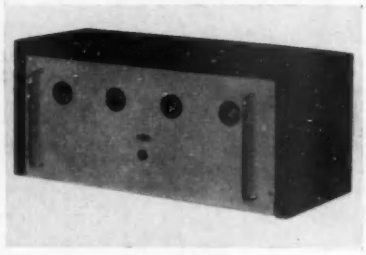
British Developments



ELECTRONIC COUNTER:

Remarkably clean design and industrial-type construction are outstanding aspects in this new British electronic counter. Surface numbered decade counter tubes simplify reading, and a front-set reset button permits return of the count to zero. These plus two rugged carrying handles are all that appear on the face of the unit.

This unit was designed primarily for counting pulses generated either photo-electrically or mechanically by contact, such as by a micro-switch. Its basic circuit comprises a pulse shaper and d-c amplifier followed by cold cathode trigger tubes and decade counter tubes.

When used specifically for photo-electric operation, a photocell circuit is incorporated in the counter as well as a d-c projector supply. The design carefully protects against any fluctuations in the a-c supply. Total power consumption of the unit in operation is 100 watts.

The standard model of this counter is suitable for 200 counts per second, but its maker advises that higher speeds can be furnished on request. *Londex Ltd., 207 Anerley Rd., London, S.E. 20 (American Agent: American Measuring Instrument Co., 21-25 44th St., Long Island City, N. Y.)*

(Circle **No. 11** on reply card)

AC BRIDGE CONTROLLER:

Electric temperature control in a range between −200 and 500 deg C is available in this fairly compact and simply designed electronic resistance thermometer. Case-mounted red and green signal lights indicate when temperature is over or below control point.

British Developments

In operation an a-c bridge is unbalanced by a signal from the temperature-sensing resistance bulb. This unbalance is fed into an electronic amplifier, which causes a relay to close an electrical circuit in the correct sequence to restore the balance. No cold junction adjustments are necessary, and leadwire from instrument to sensing bulb can be ordinary copper cable of any length and section.

Resistance bulbs used with the instrument consist of fine copper and nickle wire—pure platinum is used for high temperatures—sealed in a hard glass cylinder. Protecting tubes are supplied for some applications, and bulbs are interchangeable with an accuracy of 0.1 per cent.

The instrument itself has a front approximately 6-by-10 in., and is 7 in. deep. *Ether, Ltd., Tyburn Rd., Erdington, Birmingham, Eng.*

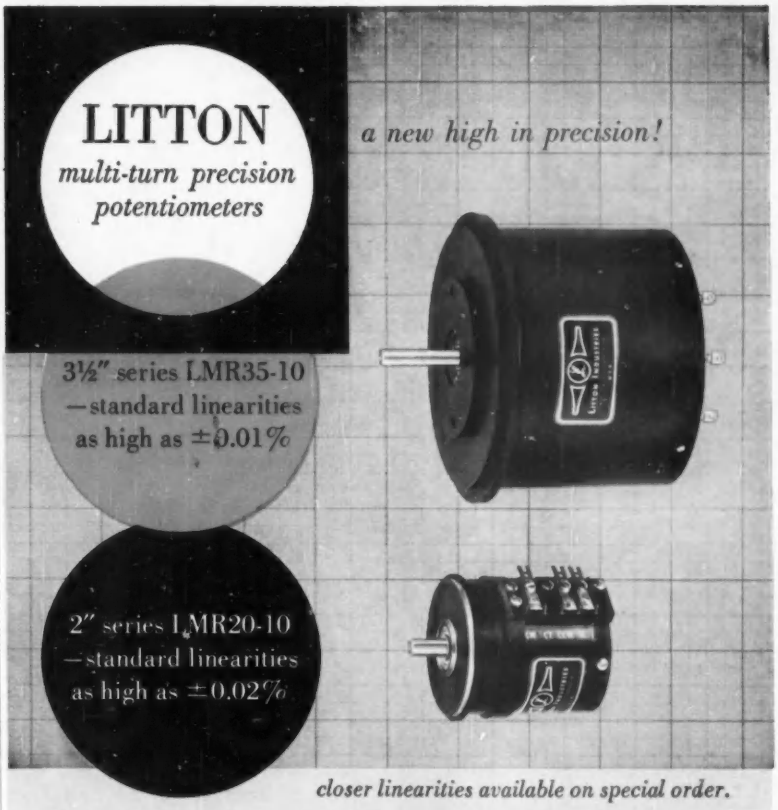
(Circle **No. 12** on reply card)

PORTABLE POTENTIOMETER has unusual range.

Here is a compact test and calibrating potentiometer claimed to offer five times the range of any similar instrument, plus an unusual accuracy of $\frac{1}{6}$ of one per cent of scale span. Hence, in addition to direct precision temperature measurement, it can be used to check a wide variety of temperature instruments. It will also measure d-c potentials up to 53 millivolts and is supplied with special scales to suit various transducers.

The new instrument is battery powered, is approximately 12-by-9-by-8 in. and weighs 12 pounds. It is sensitive to a change of 10 microvolts and has a resolution exceeding 2,000 increments. *Technique Associates, 2047 N. Parker Ave., Indianapolis, Ind.*

(Circle **No. 13** on reply card)



closer linearities available on special order.

The electrical precision expected of laboratory instruments, with the mechanical ruggedness required for dependable duty under the most severe military and industrial conditions are combined in Litton Potentiometers.

ELECTRICALLY, "ultra-precision" distinguishes Litton "pots". Recently developed high-speed, servo-controlled coil winding techniques make possible consistently high linearities. Linearity data supplied with each unit. Close total resistance tolerances can be held. For some resistance values resolution is several times that of similar models. "Infinite resolution" (stepless) pots are available.

MECHANICALLY, Litton Potentiometers are outstanding examples of precision design and ruggedized construction. All metal case—machined aluminum, anodized—is rust-proof and dust-proof. Shielded stainless steel ball bearings are standard.

DESIGN-WISE, Litton Potentiometers simplify many application and assembly problems. Extremely rugged traveling-nut type stops eliminate need for external stop assemblies for many applications. 3600° of actual electrical rotation with 90° of electrical and mechanical overtravel at each end is a unique feature. Special mountings and shafts are available as well as other electrical angles, extra tap connections, and gang versions.

Litton Potentiometers are refinements of the Series 3500 and Series 1800 ten-turn potentiometers formerly manufactured by the Birklan Corporation.

CONDENSED SPECIFICATIONS		*series LMR35-10*	*series LMR20-10*
ELECTRICAL	Independent Linearity—Standard Range	±0.5% to ±01%	±0.5% to ±0.02%
	Special Order	±0.005%	±0.01%
	Standard Total Resistance Range	1K to 300K ohms	1K to 100K ohms
	Resistance Tolerance Standard	±5%	±5%
	Special	±0.5%	±0.5%
	Actual Effective Electrical Angle	3600° +1° −0°	3600° +1° −0°
MECHANICAL	Case Diameter	3.500 inches	1.820 inches
	Starting Torque maximum at 20°C.	1.0 ±0.5 inch-ounces	0.75 inch-ounces
	Total Mechanical Angle—Nominal	3780°	3780°
	Mechanical Overtravel Each End—Nominal	90°	90°

design details subject to change without notice, certified drawings available on request.

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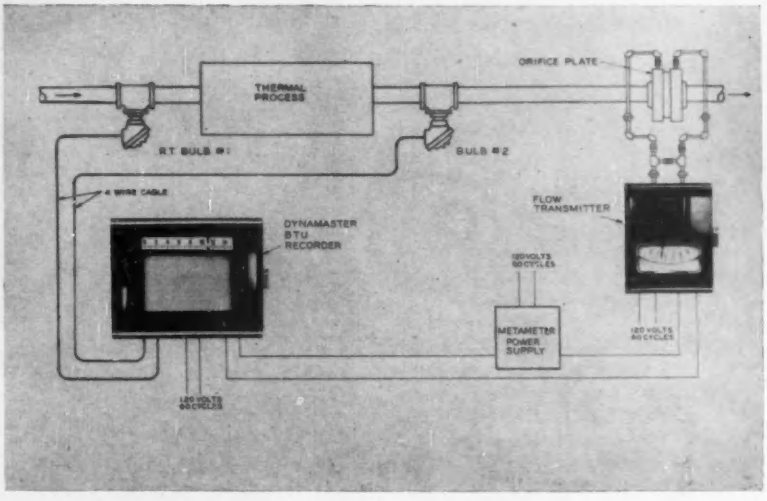
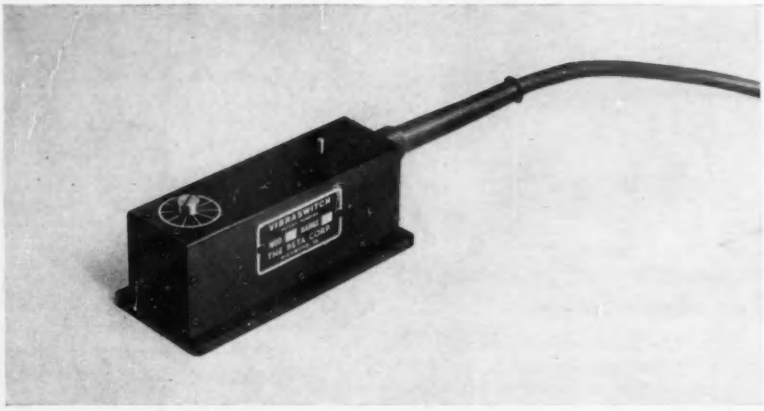


BTU COMPUTER continuously measures, records, and controls process heat transfer rate.

A single Bristol Dynamaster measures the temperature difference between one resistance thermal element located at the entrance to a heat exchanger and another located at the exit. Also receiving a flow rate signal from a flood transmitter, the Dynamaster continuously computes and records the product of temperature difference and flow rate. The product, Btu rate, is compared with desired rate to actuate control for flow rate or entrance temperature.

In addition to recording Btu rate, the Dynamaster, equipped with a second pen, records temperature difference. Totalizers are available to integrate the heat transfer rate. *The Bristol Company, Waterbury 20, Con-*

(Circle **No. 14** on reply card)



VIBRATION MONITOR, simple and inexpensive, automatically curbs vibration.

Claims are this new instrument will serve the same purpose as conventional pick-up - amplifier - power supply - relay combinations normally used for vibration monitoring—and at a cost less than $100.

The new unit incorporates a special acceleration-sensitive actuator tied in to a pre-set snap action SPDT switch. Switching action is manual reset, and can activate circuits up to 5 amp., with vibratory displacement increases as small as ten micro-in. at 12,000 rpm.

Designed to serve as a warning or shut-down control on rotating or vibrating machinery, the device has many specific application possibilities. For example, it could prevent overloading of such dynamic capacity equipment as compressors, generators, or turbines. It could also be prime element in a central station monitoring system for remote machinery.

Maximum range of the unit is 2G, or approximately 800 inches vibration per second squared. Accuracy is

claimed to be plus or minus 0.05G. Sensitivity is flat from 0 to 200 cps (12,000 rpm) and decreases gradually above this limit. *The Beta Corporation, P.O. Box 8625, Richmond, Va.*

(Circle **No. 15** on reply card)

PRECISION GRATING spectrophotometer at low cost.

Because of basic improvement in the art of making precision diffraction gratings, this manufacturer is able to offer a high quality colorimeter-spectrophotometer at a cost equal to modestly priced filter equipment.

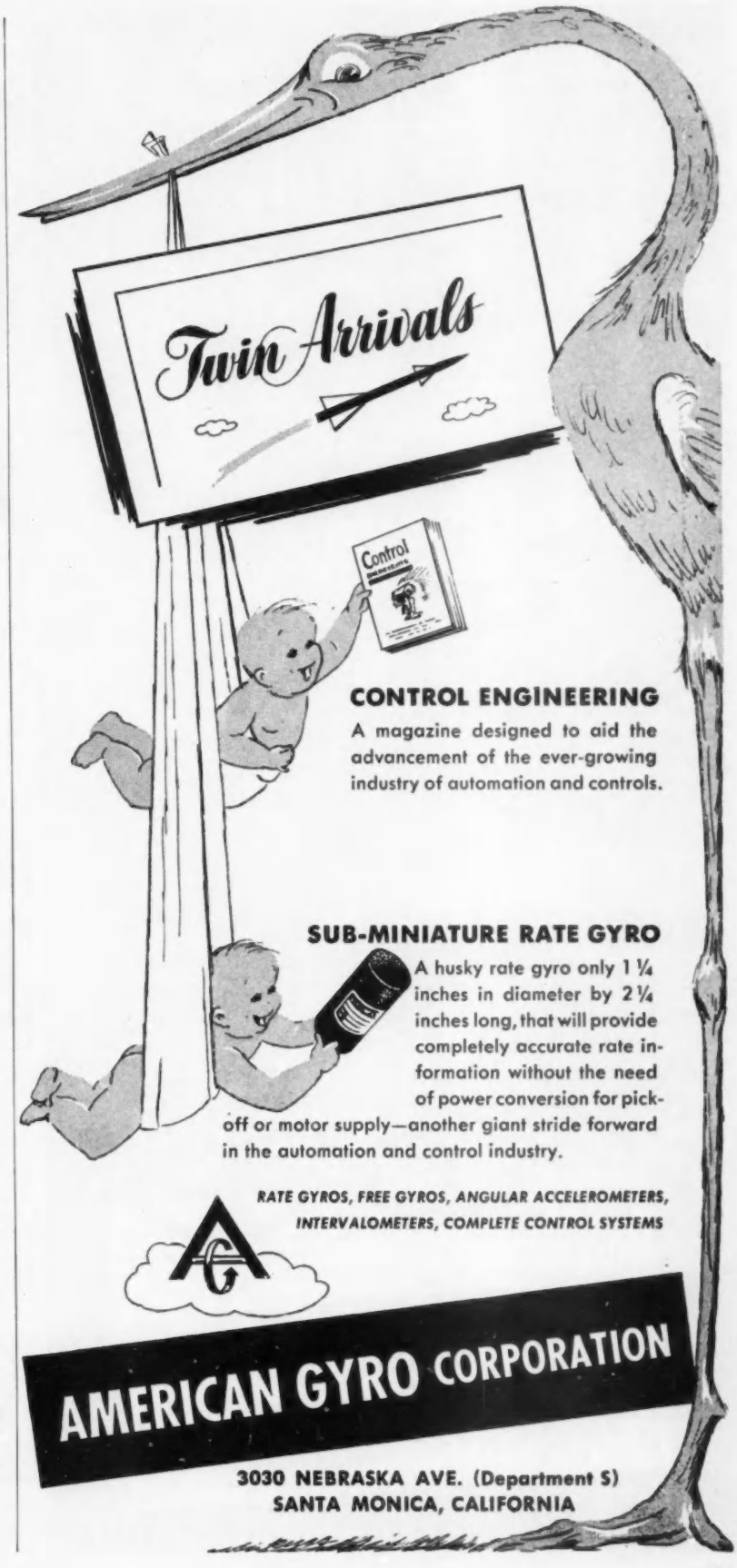
When used as a simple colorimeter, the precision diffraction grating in this instrument produces an optical beam of high wavelength accuracy and spectral purity. Two simple knob adjustments subject the liquid sample to a fixed wavelength beam and resultant reading is converted to concentration value using a calibration chart.

Excellent precision and flexibility are claimed for the new instrument in spectrophotometric work. Here the sample is subjected to light of fixed wavelength to secure transmittance or optical density readings on a double scale. Readings are then interpreted and used in construction of transmission or absorption curves.

Besides its built-in grating monochromator, the new instrument has a photo-emissive detector that converts sample-transmitted light to an electrical signal. A printed circuit amplifier is then used before the scale indicator. These components are mounted on a rigid die-cast base to minimize vibration and are in a one-piece housing.

A great advantage of the diffraction grating in wavelength selection is that it is knob-adjusted over the entire instrument range. In the new unit, effective range varies from 375 mmu (near ultra-violet) to 950 mmu (near infra-red). Infra-red tube and filter are substituted for standard tube in 650 to 950 mmu range. *Bausch & Lomb, 635 St. Paul St., Rochester, N. Y.*

(Circle **No. 16** on reply card)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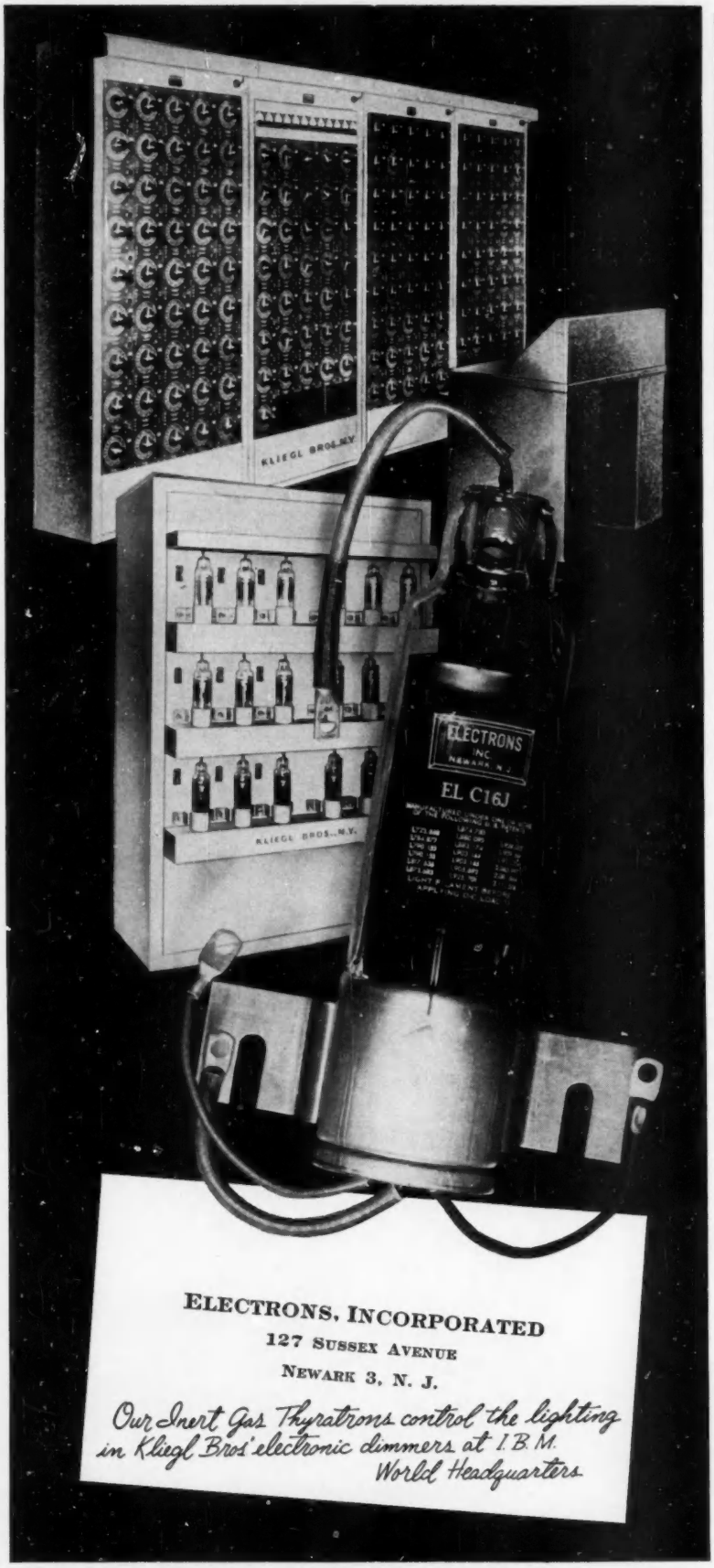

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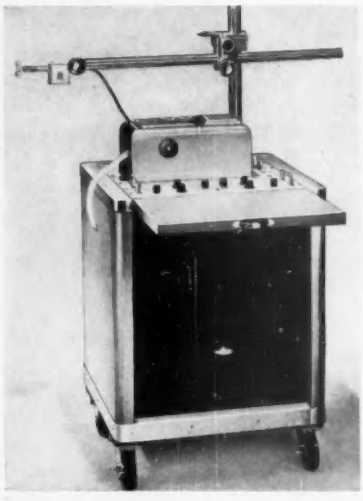


TENSION ANALYZER gages during production runs.

This mobile tester can be rolled up to the production line to measure and record dynamic tension variations in filamentary materials being processed at high speed. It is claimed to handle all textiles and fine flexible wire, and could probably be just as useful on other extruded or drawn thread-like materials.

During measurement, the strand material is looped over three pulleys of a transducer. Tension is then picked up by mechanical displacement of the center pulley. This displacement is converted into an electrical output, which is amplified and recorded on an oscillograph.

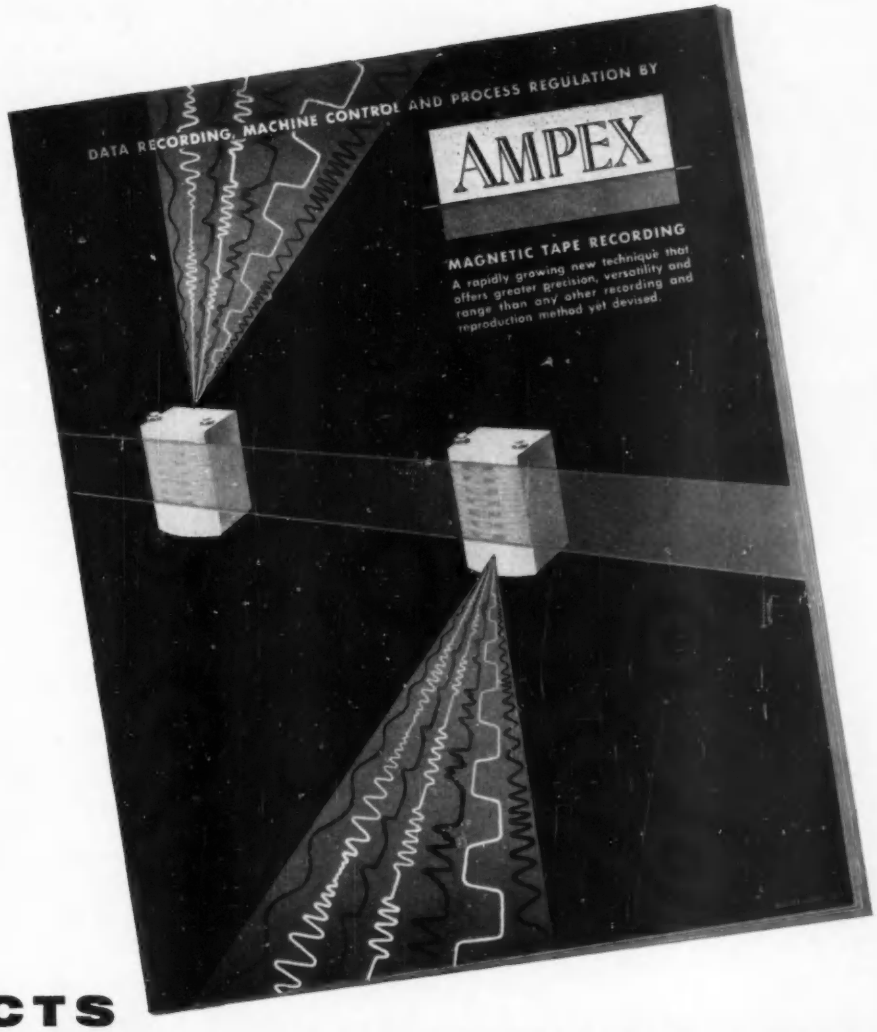
Fitting and accessories are available to position the transducer on any plane at levels from one to eight feet above floor. *Brush Electronics Co., 3405 Perkins Ave., Cleveland, Ohio.*

(Circle **No. 17** on reply card)

NYLON RESIN resists ultraviolet degradation.

A new nylon formulation which resists ultraviolet degradation is now available for equipment that must stand prolonged outdoor exposure. In addition to this special quality, this resin also has similar properties to the nylon material which has found wide use in the molding of precision gears and bearings. The weather resistant product should solve many of the field instrument and accessory maintenance problems—particularly in pipe line and petro-chemical instrumentation. *"Zytel" is a product of E. I. Du Pont Co., Wilmington, Delaware.*

(Circle **No. 18** on reply card)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SUBMINIATURE TOGGLES offer wide switching action.

Small size, with flexible switching action, make this new series of three-position, panel-mounting toggle switches of interest to control systems designers for appliances, aircraft, trains, and machinery.

Two S.P.D.T. switching elements in each unit make possible control of up to four circuits—with each basic switching related to an extreme toggle position. Also, with this double switch, it is possible to have combinations of two circuits open and two closed at any time.

Maintained toggle positions are detented and momentary spring loaded. Bushing is standard, and handles are bat type. Electrical rating is 125-250v a-c at 5 amps, and 30v d-c at 3 amps inductive. Slightly lower at 50,000 ft. *Micro Switch Div., Minneapolis-Honeywell Regulator Co., Freeport, Ill.*

(Circle **No. 19** on reply card)

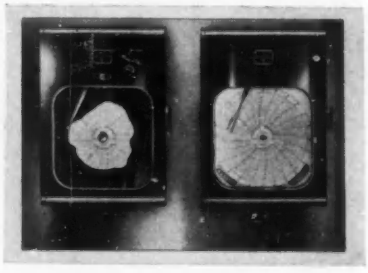
ULTRASONIC THICKNESS gage is direct reading, portable.

Thickness indication in inches with accuracies up to 0.1 per cent is claimed for this new ultrasonic gage. Portability is a feature, since its oscillator assembly is designed to be carried, along with sensing probe, by the tester—a very short length of cable between probe and oscillator being necessary in this type of high frequency circuit.

Applications for the new unit range from direct thickness testing of metals, glass and plastics to detection of flaws and poor bonding in products. A sweep-width adjustment in its large instrument scale permits thickness readings of from 0.012 to 2.5 in., with a frequency calibration for calculated readings up to 10 in.

An outstanding design aspect in the instrument is its use of a compact variable inductor rather than heavy motor-driven capacitor in the oscillator. *Branson Instruments, Inc., Stamford, Conn.*

(Circle **No. 20** on reply card)



PROGRAM CONTROL SYSTEM climatic test conditions.

A complete system of instruments is announced by Bristol for the programming of temperature, humidity, pressure or vacuum within environmental test cabinets. Accuracy of control is quoted at 0.5 per cent of full-scale value. Control actions available are: on-off and proportional, electrically; proportional, reset and derivative, pneumatically.

A plastic or aluminum cam sets the program. The cam is changed in a few seconds for another cut to a different program. *The Bristol Company, Waterbury 20, Connecticut.*

(Circle **No. 21** on reply card)

LINEAR TRANSFORMERS detect minute displacements.

Designed for the medium audio frequencies at input voltages of from 3 to 10 v., this new line of variable differential transformers will detect and accurately measure extremely small linear mechanical displacement. They can provide electrical analogy of mechanical motion from such devices as level floats, sensing bellows, surface contour pick-ups, and other physical quantities that can be converted into microlinear motion.

Output from the unit is 0.05 volts per thousandth of an inch—one mv. output would indicate a movement of 0.00002 inch. Range of core motion in one model is 0.010 in. to either side of center null position. Other core motion ranges are also available.

It appears that this device should be useful as a component in such instruments as oscilloscopes, oscillographs, and vacuum tube voltmeters. *The Gudeman Co., 340 West Huron Street, Chicago, Illinois.*

(Circle **No. 22** on reply card)

7 Reasons why Regohm is a natural for your control system

This compact, electro-mechanical controller provides sensitivity, speed of response and system stabilization under severe operating conditions. Its design and operating features have made Regohm useful for automatic control systems in which heavier, more expensive and complex, but less accurate equipment had previously been the only available solution.

(1) **SMALL SIZE** · Regohm is a compact, plug-in device; lightweight, extremely rugged and position-free. The unit's small size does not limit its power-handling capacity. This makes Regohm a "natural" where economy of space and weight are your major considerations.

(2) **POWER AMPLIFYING** · Regohm is a high-gain electro-mechanical power amplifier. Milliwatt variations in signal energy can control energy changes millions of times greater.

(3) **IMPEDANCE MATCHING** · Signal and controlled circuits are isolated, both electrically and structurally. Signal coils may have ratings from 0.01 to 350 amperes. Controlled resistors on a panel in which Regohm is plugged, can have values from zero to infinity, depending on the controlled system.

(4) **SYSTEM STABILIZING** · A thoroughly reliable, sturdy dashpot aids in system damping. It can easily and readily be adjusted over a wide range to match the dynamic characteristics of the Regohm to those of your present system.

(5) **ANALYTICALLY DEFINABLE** · The response of Regohm is independent of the rest of the servo system. Its response characteristic can be expressed in terms of conventional "transfer functions." Regohm acts as an integrating error-rate proportional controller. No appreciable steady-state error can occur. Regohm's effect can be calculated in advance, simplifying the design and facilitating the prediction of performance.

(6) **CONTINUOUS CONTROL** · In "closed loop" systems a high-speed averaging effect occurs as Regohm's armature oscillates over a small amplitude. This provides intermediate values between step resistances and results in continuous, stepless control in systems operating at power frequencies and below.

(7) **LONG LIFE** · In properly engineered installations, Regohm's life is measured in years. Plug-in feature simplifies replacement and maintenance—there are no parts to renew or lubricate. Shelf life is substantially unlimited.

Our engineering and research facilities can help you apply Regohm to your servo system or regulator problem. Write for Bulletin 505.00, analyzing Regohm's characteristics and applications. Address Dept. A, ELECTRIC REGULATOR CORPORATION, *Norwalk, Connecticut.*

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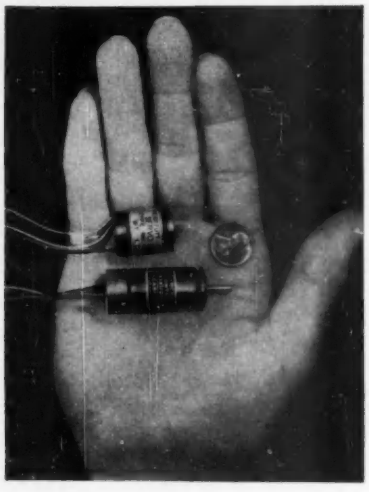


MINUTE SERVO COMPONENTS perform like big ones.

These new miniature servo motors and synchros measure only ¾ inch in diameter, yet are claimed to perform with an accuracy and power usual in units twice as large. Also offered are similar sized synchro transmitters, control transformers, and differentials for use in conjection with these tiny motors.

A feature in the motors is a straight-through bore and integral stator-housing. Stainless steel is used in housing, laminations, and in necessary ball bearings. A "potted" stator construction is used to seal hermetically the motor windings.

The small servo motor illustrated measures ¾ inch diameter by 1⅜ inch long. It has a no-load speed of 6,500 rpm and a stall torque of 0.1 ounce-inches. Its power input is 1.5 watts, with a voltage input of 18 V. Weight is 1.2 ounces.

Another equally small motor is available with high inherent damping for simple instrument servos. Also, a potted servo amplifier—about the size of a cigarette pack—and miniature precision gear trains complete a line of components which should be extremely useful in the design of very compact, but precise servo systems. *Kearfott Co., Inc., 1378 Main Avenue, Clifton, New Jersey.*

(Circle **No. 23** on reply card)

PLUG-IN PULSE TRANSFORMER kit aids circuit designers.

Now available is a pulse transformer kit which contains ten plug-in transformers to fit a standard 7-pin socket. Function of this kit is to permit circuit designers to quickly run through a variety of units and select the proper

type for a particular job. The ten transformers cover a pulse width range of from 0.1 to 23 microseconds. Each unit is one inch high by ⅜ in. O.D. or 11/16 O.D. All are hermetically sealed and meet MIL-T-27 specifications. *PCA Electronics Inc., 2180 Colorado Ave., Santa Monica, Cal.*

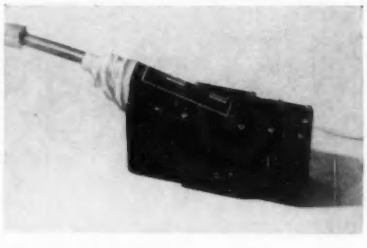
(Circle **No. 24** on reply card)

DECADE TUBE handles 20,000-count input.

This cold cathode counting tube handles an input of 20,000 counts per second. It employs ten radially-spaced cathodes and its toll is directly visible on a top-mounted number bezel designed for surface display on the counting apparatus.

The new tube operates on 420 volts d-c and has an anode current of only 800 microamps. Its length is 3.87 inches and diameter, 1.12 inches. *Atomic Instrument Company, Cambridge, Massachusetts.*

(Circle **No. 25** on reply card)



GENERATOR converts force to electrical pulse.

An off-shoot of military development, this new transducer converts mechanical force into pulses of electrical energy. Its military prototype saw use in aircraft as an emergency stand-by actuating unit to set off explosive charges for forceable ejection of external stores and bombs.

Makers of the device see broad possibilities in such non-aircraft applications as mining, railway signalling, operating flash equipment, alarm systems—in fact, wherever an electrical impulse is required and only slight mechanical force is available.

The unit is self restoring after operation. It is hermetically sealed and will operate under water or in troublesome atmosphere. Size is 5¼ long by 2-in. wide by 3¾ in. long, and weight is 2 lbs. 12 oz. Power output is 5½ x watts for pulse duration of 25 milliseconds or longer, with fast rise time and minimum pulse lag and decay. *Microloc, 5811 Marilyn Ave., Culver City, Calif.*

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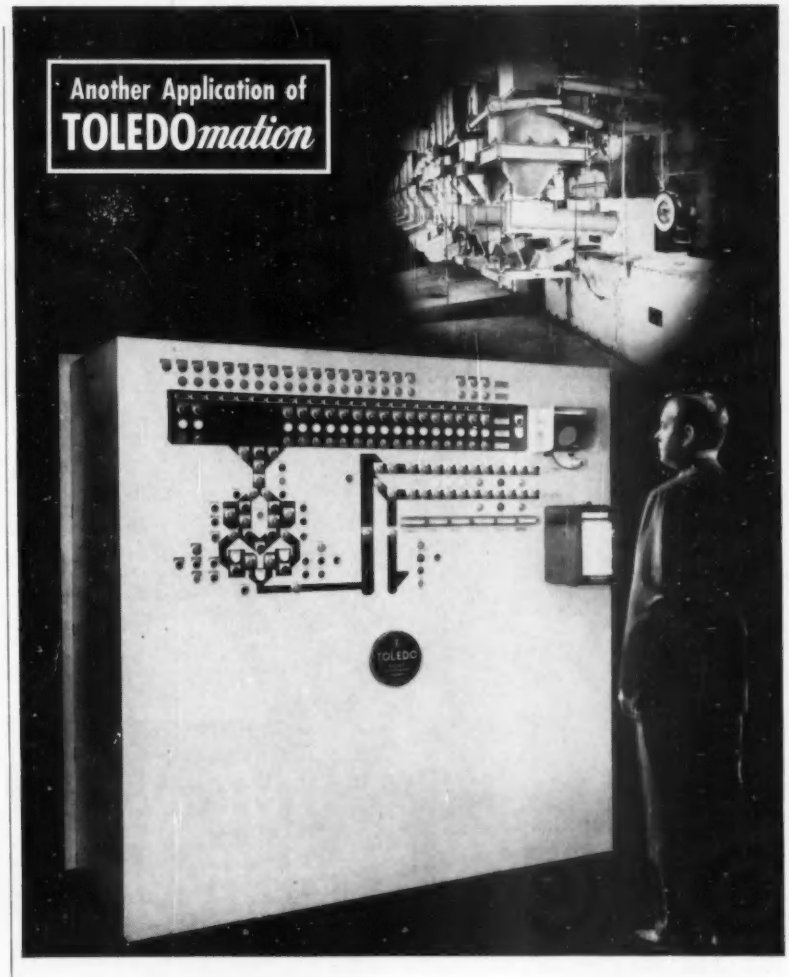

PROBLEM SOLVED BY:

Automatic, Electrically-Interlocked Batch Control

A pattern of flashing lights traces the precise compounding of ingredients by a battery of Toledo Scales—all electrically interlocked through this control panel. Each ingredient is accurately added, in proper sequence. The resulting batch is controlled all the way through surge bins and mixing to the furnaces without chance of human error. This example of TOLEDOmation is one of a great variety of automatic units developed by the Toledo custom-engineering staff, combining traditional Toledo Scale accuracy with advanced applications of electrical and electronic equipment.

What is your problem? The custom-products staff at Toledo, and at Toledo offices throughout the country, is available to study your particular needs in testing, classifying, batching, counting, balancing, and force-measuring. Check with our office nearest you or write Custom Industrial Products, Toledo Scale Co., Toledo 1, Ohio. A new booklet describing recent applications of TOLEDOmation will be available soon. Write for a copy.

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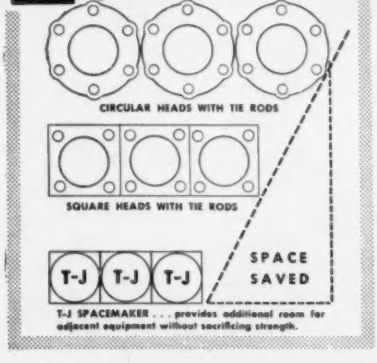
CIRCULAR HEADS WITH TIE RODS
SQUARE HEADS WITH TIE RODS
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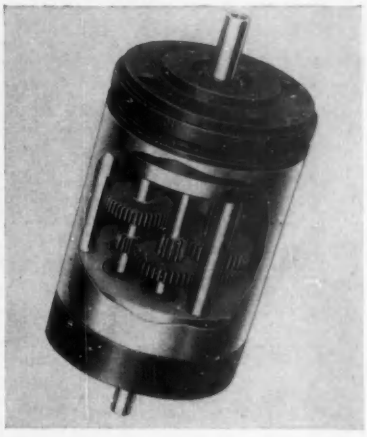
SPACE SAVED
T-J SPACEMAKER . . . provides additional room for adjacent equipment without sacrificing strength.

Now the sensational new T-J Spacemaker sets the pace in compact cylinder design and efficient performance!

New "Self-Aligning" adjustable oil cushion means faster acceleration and better cushion than ever before . . . New T-J Super Cushion Flexible Seals for air insure positive cushion with automatic valve action for fast return stroke.

More plus features include—heavy wall, precision honed, hard chrome plated, seamless steel body . . . leakproof cylinder head to body construction . . . heavy duty, high-tensile, *hard chrome plated piston rod.* Write for bulletin SM-454-2. The Tomkins-Johnson Co., Jackson, Mich.

T-J TOMKINS-JOHNSON
RIVITORS AIR AND HYDRAULIC CYLINDERS CUTTERS CLINCHORS



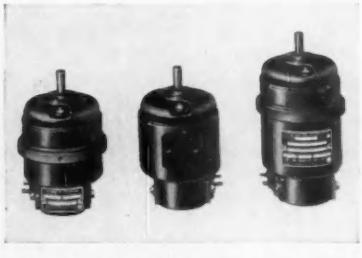
MINIATURE SPEED REDUCER has minimized backlash.

Lightness coupled with fairly large output torque make this new series of precision miniature speed reducers especially interesting to designers of electronic controls, actuators, and servo systems.

All dimensions in this series are less than two inches. Ratios range from 12.5:1 to 10,000:1, and output torque loads from 25 to 100 inch-ounces are possible. Special design has also lessened backlash to less than one-half degree.

Gears in these units are cut to A.G.M.A. Precision 2 tolerances from stainless steel, or from aluminum bronze wherever very quiet operation is needed. *Bowmar Instrument Corp., 2415 Pennsylvania Street, Fort Wayne, Indiana.*

(Circle **No. 27** on reply card)



DC TACHOMETER generators are small in size and price.

Offering speed from 50 to 5000 rpm, this new line of commercial grade permanent magnet dc tachometer generators is claimed to be more compact in design and priced almost ⅓ less than comparable units built to meet military specifications.

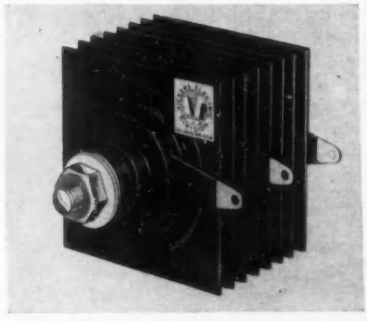
Two sizes in three frames are available. Two types, measuring 3¼ in. long and 2¼ in. in diameter, are for

flat and flange mounting and produce an output of 1 volt per 100 rpm. The other size is slightly larger, and is equipped for both flat and flange mounting. Output of the largest is 3 Volts per 100 rpm.

In all units, tolerance on output voltage is plus or minus 10 per cent, and output is lineal with speed at constant ambient temperature. At steady speed, output is constant within plus or minus 0.5V for rotation in either direction.

Frames are die-cast aluminum, and a stainless steel shaft of 0.250 in. diameter with $\frac{3}{8}$ in. extension is employed. Armature and commutator is an 11-shot design, with silver-graphite brushes and vacuum impregnated Formvar-type windings. *Instrument Motors, Box 5, Stamford, Conn.*

(Circle **No. 28** on reply card)



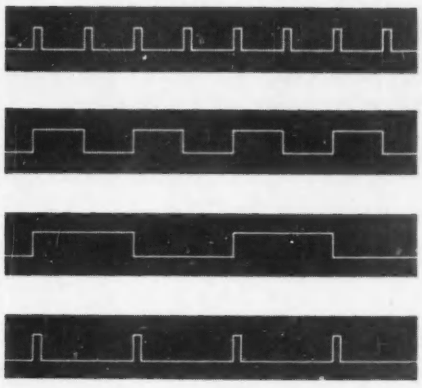
40-VOLT SELENIUM RECTIFIER has low leakage.

Unique electrical design is in this new selenium rectifier—one of the first, claims its manufacturer, to have an inverse rating of 40 volts. It combines this high breakdown value with low leakage (an estimated 2 milliamperes per sq. in. average) and low inverse loss.

Heating in the new unit, as a result of low inverse loss at high voltage, has been found to average less than 5 deg. C. Also, an inherently high dielectric quality is claimed to enable it to withstand surges up to twice its rated voltage. It will operate in ambient temperatures up to 125 deg. C. and show no derating at 50 deg. C.

An extensive program of life tests now past the 25,000-hour mark is still being given the new unit. It is believed that this excellent performance is due to a newly-developed, inherently stable inorganic barrier. In fact, inverse characteristics seem actually to improve with use. *Vickers Electric Division, 1817 Locust St., St. Louis 3, Mo.*

(Circle **No. 29** on reply card)



Burroughs
PULSE equipment
lets you assemble
your own system—
IN MINUTES

Just by connecting standard cables between Burroughs Pulse Control units, you can assemble virtually any pulse system you want.

Suppose you need a complex pulse sequence for testing. The basic units required to make up the system can be ordered from Burroughs—and delivered from stock. Connect them together, and there's your system. You've saved time-consuming "breadboard" engineering, equipment cost, and delay on your primary project. What's more, your Burroughs Pulse Equipment can be used over and over again on different, future projects.

To meet the growing need for versatile pulse control systems, Burroughs offers a whole family of matched pulse handling units: pulse generators, coincidence detectors, flip-flops, gating circuits, etc. During the past four years, this equipment has been in use by such prominent organizations as MIT, Consolidated Engineering Corp., Wayne University, Stanford Research Institute, and many others.

Let us help you get started quicker on pending engineering work. Write us a letter outlining briefly your pulse system requirements. Dept. 9-J, Electronic Instruments Division, Burroughs Corp., 1209 Vine St., Philadelphia 7, Pa.

ELECTRONIC INSTRUMENTS DIVISION
Burroughs
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- DATA CONVERSION SYSTEMS
- MAGNETIC TAPE HANDLING EQUIPMENT
- MAGNETIC READING AND RECORDING CIRCUITS
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3C Engineers now operate and maintain a large-scale digital computer for the U.S. Navy.

Send inquiries to Department L4 . . .

3C COMPUTER CONTROL CO. INC.

92 BROAD STREET, BABSON PARK 57, MASSACHUSETTS

NEW PRODUCTS

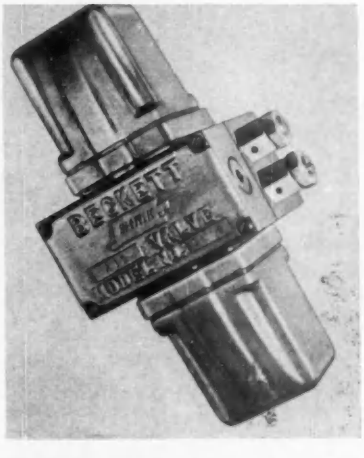
CRYSTAL PHOTOCELL operates relays without amplifier.

Ability of this extremely small cadmium sulphide crystal photocell to operate inexpensive relays without an amplifier suggests its use in more compact, less costly photo-electric instruments and devices.

Size of the new sensing element is only ¼ in. in diameter and ¼ in. deep. Yet it will deliver from 2 to 5 milliamperes when exposed to light of from 50 to 100 foot-candles when approximately 100 volts is across cell and load. Further, it will respond to ultra violet, x-rays, and nuclear radiations as well as visible light and is sensitive to changes in intensity as low as 0.0001 foot-candles.

Resistance in this crystal pick-up decreases linearly with increase in illumination from 10 to 100 foot-candles. Dark resistance is approximately 10,000 megohms and maximum resistance variation with temperature is 2-to-1 between minus 50 to plus 75 deg. C. *Standard Piezo Company, Carlisle, Pennsylvania.*

(Circle **No. 30** on reply card)



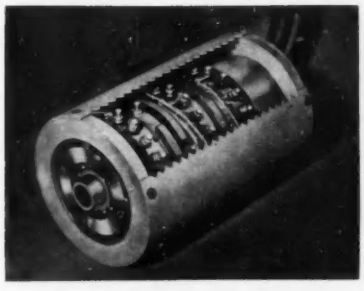
SOLENOID VALVES make quick replacement simple.

Featuring a built-in junction box and quick disconnections, this new line of solenoid valves can be removed from control systems without upsetting the electrical circuit. Also, valve manifold construction is set up to permit rapid replacement of all critical parts—including body and spool assembly—without disturbing piping on the main manifold block.

The new valves are available for air and other non-corrosive gas, or for oil and water hydraulics. They are avail-

able in 3-way, 4-way, two- or three-position, in $\frac{1}{8}$, $\frac{1}{4}$, $\frac{3}{8}$, and $\frac{1}{2}$ inches nominal NPT sizes. Actuators include single and double solenoid, piloted, hand lever, cam roller. Detent and spring load to center are supplied on 3-position models. *Beckett-Harcum Company, Wilmington, Delaware.*

(Circle **No. 31** on reply card)



POWER DIGITALIZER works without vacuum tubes.

This device converts shaft positions directly into digits. It should provide a flexible and highly useful link between analog and digital equipment, as well as an actuator for summary punches, relays, and similar equipment.

High power capacity comes from separating digitalizing and power circuits. Ball bearing construction provides low operating torque. And the lack of vacuum tubes adds to the general ruggedness of the device, which is only 3.5 inches in diameter and 5.7 inches long. *EE Division, Oerlikon Tool & Arms Corp. of America, Asheville ,North Carolina.*

(Circle **No. 32** on reply card)

SMALL DIAMETER BELLOWS have high pressure rating.

Better methods are held responsible for a line of tiny, precision metal bellows which should be welcomed by engineers involved in the design of miniature instruments and components. These bellows run down in size to $\frac{1}{4}$ inch diameter, with a wall thickness of only .002 inch. They will, however, withstand an external pressure as high as 2300 lbs.

Materials used are brass, phosphor bronze, beryllium copper, and monel. Quantity production is claimed to make their price attractive. *Bridgeport Thermostat Division, Robertshaw-Fulton Controls Company, Bridgeport, Connecticut.*

(Circle **No. 33** on reply card)

Not Only a Time Delay Relay...

...with performance features never before possible

G-V THERMAL RELAYS

Advanced Engineering Features!

- Miniature and Octal Sizes
- Hermetically Sealed in Metal Shell
- Adjustable and Non-Adjustable
- Heater Voltages up to 230 Volts
- Fully Temperature Compensated
- Suitable for Military and Industrial Use
- Unequalled for Ruggedness and Precision

More and more engineers are finding other uses for these precise and rugged units—jobs which thermal relays of the usual bi-metal design often cannot do... such as:

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- POWER SUPPLY OVERLOAD PROTECTION
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Only G-V offers complete technical data and helpful engineering cooperation on THERMAL TIME DELAY RELAYS.

Greatly expanded production facilities assure prompt deliveries.

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Electrical Noise in Wire-Wound Potentiometers

BY IRVING J. HOGAN

Research and Development Division
Helipot Corporation

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387

Helipot *first in precision potentiometers*

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potentiometer type transducers for use at temperatures between −60°C. and +160°C.

Designs available permit single or multiple range linear output from non-linear input function, and operation over wide ranges of environmental conditions.

for
- PRESSURE
- ALTITUDE
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Designs available for operation to 285°C.

Request Catalog #653.

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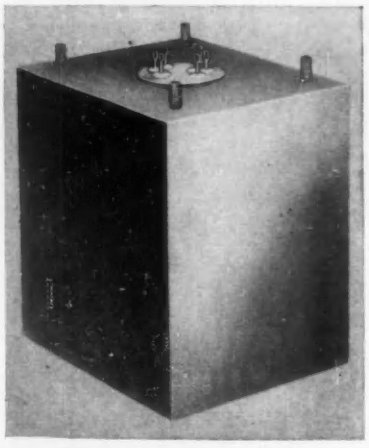


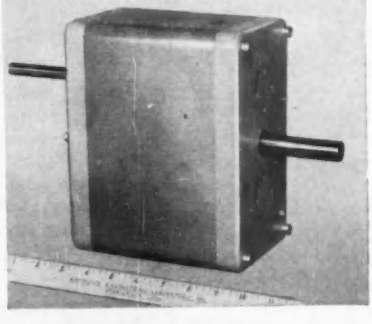
MAGNETIC SERVO AMPLIFIER has one-cycle response.

Here is a neatly styled magnetic amplifier which features one-cycle response. It thus appears well suited for many medium performance indicating or position type servomechanisms that need no pre-amplification. Addition of a simple pre-amplifier would suit it for control systems that demand great accuracy.

One-cycle response actually insures the widest possible output band-width consistent with use of 60 cps as power supply frequency. This removes many of the stabilization problems which formerly marred magnetic amplifier performance in servo systems.

The new unit delivers 10 watts reversible phase output for reversible phase ac or reversible polarity dc input. *Polytechnic Research & Development Co., Inc., 202 Tillary Street, Brooklyn 1, New York.*

(Circle **No. 34** on reply card)



MAGNETIC FLUID transmission for link in servo systems.

Magnetic clutches act as sinews in this variable-torque, selective rotation transmission which can function between prime mover and load in a servo actuator. It displays unusual power—

350 inch pounds at output shaft—in a compact package. The device measures 14-by-8¾-by-4¾ in. and weighs 37 pounds.

Clutch elements are side-by-side in the unit and drive in opposite directions from input shaft and back-to-back gearing. Output to shaft is by a 5:1 speed reduction through pinions meshing with a common gear. Direction and magnitude of transmitted torque depends on which clutch is energized and amount of d-c current.

At the recommended input speed of 650 rpm the clutch element will transmit 542 watts—or approximately ¾ hp. This offers an unusual power gain of 31 in a fairly small unit. *Raymond Engineering Laboratory, Inc., Middletown, Connecticut.*

(Circle **No. 35** on reply card)

PRECISION CAMS designed in "package" for users.

Individual engineering goes into these highly machined cams—offered individually or in "package" form, complete with followers and gearing to meet the user's specifications.

Two major types of cam are offered —three-dimensional and single-input. The former is designed to simulate an arbitrary function, formed by two independent variables. Bomb characteristics and navigational data are typical functions which have been cut. The single-input cams are designed to bear a non-linear relation to another single motion or function. These simulate logs, ballistic data, trigometric functions in output.

As can be gathered from the above, these cams could serve especially well "memory" devices for analog computers and similar systems. *Ford Instrument Company, 31-10 Thomas Avenue, Long Island City, New York.*

(Circle **No. 36** on reply card)

FEEDBACK FANCY

Needed: Automatic hearing-aid control.

Suggested: Simple feedback that modifies input inversely to sound could mute loudmouths, tune-in whisperers.

BIDDLE *Instrument News*

See These NEW BIDDLE PRODUCTS at the International Instruments Show

FRAHM® RESONANT REED RELAYS AND OSCILLATORS
A team of instruments for controlling, signaling, monitoring, speed protection, and frequency matching. (BULLETINS 33-CE and 34-10-CE)

BIDDLE IMPULSE CABLE FAULT LOCATING TRANSMITTER
Model 5, 5 KV, 16 MUF for proof testing and locating faults on important cable in the 2500 volt delta and 4000 volt wye insulation class. (BULLETIN 65-CE)

BIDDLE CORONA TESTING EQUIPMENT
for non-destructive evaluation of electrical insulation. Safe, simple and reliable. Does not require engineering personnel. (BULLETIN 66-CE)

BIDDLE MOTOR AND PHASE ROTATION TESTER
for determining direction of rotation of electric motors before they are connected to the line. Also, to determine phase rotation or sequence of energized power circuits. (BULLETIN 80-CE)

BIDDLE DIELECTRIC TEST SET
Model 1-40 KV for measuring d-c current at voltages up to 40 KV when applied to the insulation of such equipment as generators, transformers, bushings, and cable. (BULLETIN 22-CE)

Biddle Instruments and miscellaneous laboratory equipment cover a wide field of electrical and scientific testing, measuring and experimental work. Our research and development engineers are constantly working to bring you accurate and dependable instruments to better meet the mounting problems of this fast moving age. Basic products in the Biddle line include Megger® Electrical Testing Instruments for measuring insulation resistance, Ohmmeters for low resistance tests, and Ground Testers; the Biddle Ionization Test Set; Transformer Turn Ratio Test Set; Frahm® Resonant Reed Tachometers, Relays and Frequency Meters; Jagabi® and Dr. Horn Tachometers; Jagabi Rheostats; Pointolite Lamps; Kipp & Zonen Galvanometers, etc.

Write for BULLETIN 19-54-CE

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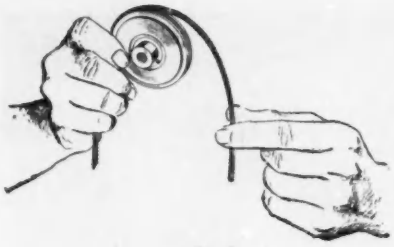


A new key to Accuracy...

MECHANICAL *FEEDBACK* CONTROL LINKAGES

The unusual cable shown above is Teleflex—the unique "flexible rack" that is helping to solve mechanical motion problems in servomechanism design.

Take an example in the jet engine field . . .

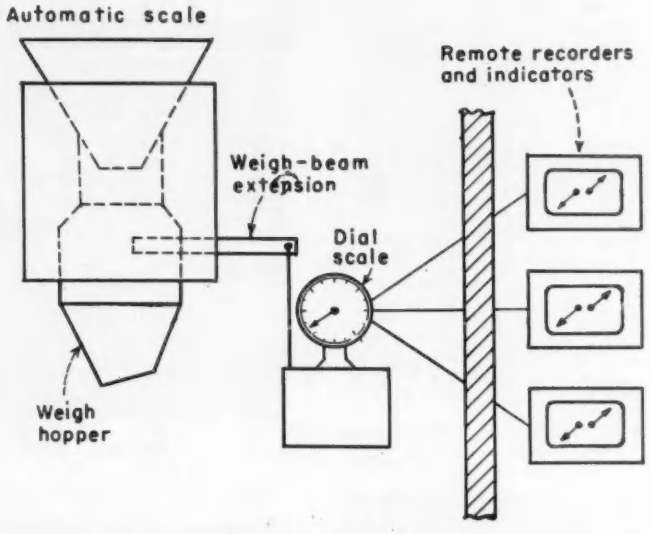
PROBLEM: A highly accurate mechanical feedback linkage is required to complete a servo system loop. One end of the system is exposed to a 350°F ambient temperature.

SOLUTION: A special control box was designed, with a hobbed wheel to engage the Teleflex cable. A spring-loading feature allows for a selection of spring loads up to 25 pounds, applied in either direction, depending on the individual mounting arrangement or system load. One system over 100 inches long, with 270° of bend, had only .022 inches of backlash. Under more favorable bend and length conditions, another system held backlash down to .005, using a similar control box.

Teleflex tubular conduit, routed along contours and around obstructions, guides the cable to remote locations, duplicating the motion at both ends of a system.

DESIGN ENGINEERS—Complete descriptive information is in Catalog 500 L. Write for your copy to Teleflex, Incorporated, 125 S. Main St., North Wales, Pa.

TELEFLEX
MECHANICAL CONTROLS
LINKAGES MECHANISMS



REMOTE INDICATORS meet high accuracy standards for automatic weighing.

Miniature indicating and recording units were designed to meet the high accuracy standards demanded by automatic industrial weighing systems. They offer accuracies of one part in 2,000.

In weight control—as illustrated above—these remote units precisely follow a prime-mover scale. In operation, material weight to the weigh hopper is indicated on the dial scale and a 60-cycle servo system duplicates this reading on the remote panel. The servo system consists of a synchro transmitter, amplifier, servomotor, and control transformer. *Richardson Scale Company, Clifton, New Jersey.*

(Circle **No. 37** on reply card)

RESOLVER AMPLIFIER: Characteristics of new resolver amplifier to work with Ketay Model D13820 resolver have just been announced. *Ketay Manufacturing Corp., 555 Broadway, New York 12, N. Y.*

TYPICAL OPERATING CHARACTERISTICS

		Phase Shift (Minutes)	*Magnitude Variation*
Frequency (cps) $380 < f < 420$		±1	±0.0002
Input Voltage	14 v	+0.3−0	+0.0004−0
	1 v	+1.2−0	+0−0.0015
	0.25 v	+2.0−0	+0−0.003
Ambient Temp. $-55 < T < +75°C$		±1	±0.001

ELECTRICAL CHARACTERISTICS

Frequency	400 cps
Voltage Range	¼ - 14 v
Power	
B +	10 w (150 v)
Fil.	9.5 w (6.3 v)
Channels	2
Gain Margin	9 db (low and high freq.)
Phase Margin	35 deg (low and high freq.)

(Circle **No. 38** on reply card)

FEEDBACK FANCY

Needed: Some kind of arm-mounted device could sense blood factors relating to body energy and sound the alarm.

Suggested: "Fatigue indicator" that tells the busy executive when to slow down or take that vacation.

Potter & Brumfield

offers you the benefits of

20 years' custom engineering

...with more than 110 Basic Relay Types!

These basic relay types have been evolved from the design and production of more than 15,000 different custom relays. Used as they are or with slight modifications they will fit most any and all applications.

Thus you are assured of:

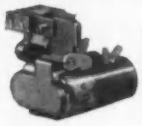
1. **Proven Design**—P & B standard relays have been field tested under all kinds of conditions, thereby giving long, trouble-free service.
2. **Lower Costs**—Because these relays are already tooled and manufactured in production quantities—a substantial cost saving is passed along to you!
3. **Fast Delivery**—Orders for standard relays can be filled from stock or with minimum delay.
4. **Available through Distributors**—Standard types available through P & B franchised Elecironic Parts Distributors in all principal cities.

Potter & Brumfield engineers are available for consultation on special relay problems—design or application.

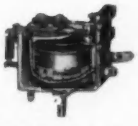
A FEW OF THE MORE THAN 110 P&B STANDARD RELAY STRUCTURES

POWER RELAYS Two series—heavy and medium duty. For across the line power circuits, high current or high voltage switching. From SPST to 3PDT.

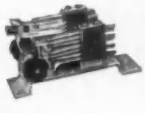
PLATE CIRCUIT RELAYS Actuate on a few milliwatts. Easy to adjust. Small—rugged—low in cost. From SPST to DPDT.



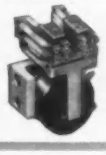
SUPER SENSITIVE RELAYS Operate on less than 10 MW. Dual coils, 10G vibration resistance. Wide versatility. One from C-SPDT.



GENERAL PURPOSE RELAYS For applications where space and weight are important. Withstand high shock and vibration. From SPST to 3PDT.

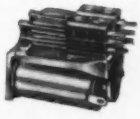


IMPULSE RELAYS Automatic stop prevents backlash or overtravel. Precise switching regardless of operating speed.

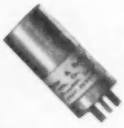


400 CYCLE AC RELAYS 15 gram or higher contact pressure. Withstand better than 10G shock. Heavy cast mounting foot. One form A to 2 form C.

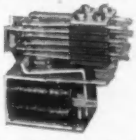
MULTIPLE CONTACT RELAYS Longer coil gives power to actuate additional contacts and maintain 15 grams pressure. From SPST to 3PDT.



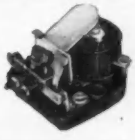
TELEPHONE RELAYS Four series meet practically all telephone type relay requirements. Short armature movement, long armature arm. Many contact combinations.



SUPER MIDGET RELAYS Tiny and rugged—plug in—one form C. High degree of resistance to vibration and shock.

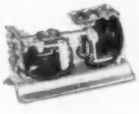


MULTIPLE LEAF RELAYS For multiple circuit switching of power loads. Contact springs heavy tin-coated phosphor bronze. From SPST to 4PDT.

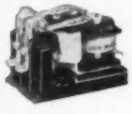


MOTOR STARTING RELAYS Voltage controlled to insure throwout of starting winding when motor reaches rated speed. Fast acting double break.

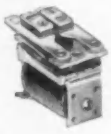
SUBMINIATURE SENSITIVE RELAYS Standard 7 pin plug-in. Ruggedized for vibration and shock. Operating power 25MW. Contact load 2 amps.



LATCHING RELAYS Compact—high contact capacity. Coils for either AC or DC current or voltage operations. From SPST to 4PDT.



HEAVY-DUTY SHOCK-PROOF RELAYS Can be mounted in any position. Particularly resistant to vibration and shock. From SPST to DPDT.



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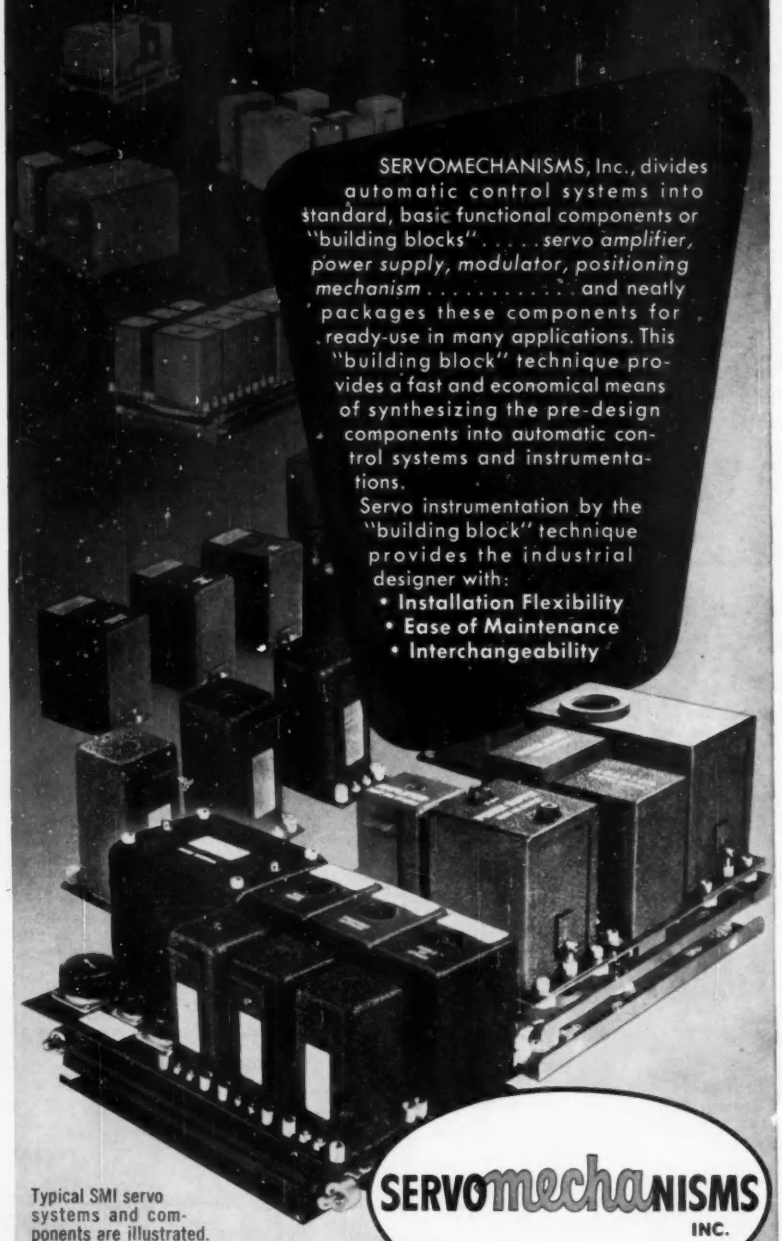

SERVOMECHANISMS, Inc., divides automatic control systems into standard, basic functional components or "building blocks" . . . . . *servo amplifier, power supply, modulator, positioning mechanism* . . . . . and neatly packages these components for ready-use in many applications. This "building block" technique provides a fast and economical means of synthesizing the pre-design components into automatic control systems and instrumentations.

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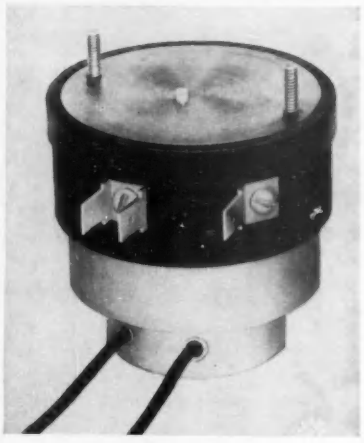

PUSH-BUTTON TIMER has wide operating range.

This new motor-driven timer has a surface mounted start-stop button which can control an application load during a factory-set time interval of anywhere from 15 seconds to one month.

The timer is enclosed in a 2¼ by 2⅛ in. deep dust-tight housing and can be mounted to operate in any position. It has quick connect terminals, heavy duty solid silver contacts, and a nylon cam. Electrical rating of its motor is 25 amp. at 115/60 A.C. *Bristol Motor Division, Vocaline Company of America, Inc., Old Saybrook, Conn.*

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HOLDING COIL acts as switch, pilot, and relay.

This new holding coil switch adds the function of relay to two switching actions in a car cigarette-lighter size. Secret of this action is a built-in solenoid that holds the switch on contact until its solenoid coil circuit is externally interrupted by a pulling force at the switch knob.

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3	10	17	24	31	38	45	52	59	66	73	80	87	94
4	11	18	25	32	39	46	53	60	67	74	81	88	95
5	12	19	26	33	40	47	54	61	68	75	82	89	96
6	13	20	27	34	41	48	55	62	69	76	83	90	97
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(51) SPECIAL PURPOSE MOTORS. Kollsman Instrument Corp., Catalog, 88 pp. Describes electrical and mechanical characteristics of latest developments in line of servo components. Items covered include induction motors, induction generators, motor generators, synchronous motors, Circutrols and Teletorques.

(52) RECORDING CONTROLLER. General Electric Co., Catalog GED-2100A, 18 pp. Describes line of potentiometric and ac bridge recorders and recording controllers. Units feature magnetic standard. Pneumatic control forms give proportional plus reset and proportional plus reset plus rate control action.

(53) OSCILLOGRAPHIC RECORDING SYSTEMS. Sanborn Co., Catalog including bulletins 1 to 11, 34 pp. Gives mechanical and electrical data including frequency response on 1-, 2- and 4-channel recording systems, amplifiers, ac and dc preamplifiers, Triplexer, threshold monitor, galvanometer and recorder assemblies.

(54) PROCESS STREAM ANALYZER. Perkin-Elmer Corp., Bulletin, 6 pp. Covers TRI-NON analyzer for continuous in-plant process stream analysis. Principles of operation, detailed specifications and discussions of typical applications are included.

(55) ELECTRONIC DATA PROCESSING. Remington Rand Inc., Bulletin EL 179, 12 pp. Discusses the role of general purpose digital computers in automatic control and information systems. The ERA 1103 computer is described, with emphasis on features that give it desirable real-time properties.

(56) HIGH-PRECISION TEST INSTRUMENTS. Wm. Miller Instruments, Inc., Brochure 105-5-54, 4 pp. Describes a line of instruments for multi-channel recording of static and dynamic test data including oscillographs, galvanometers, amplifiers, analog computers and function generators.

(57) CONTROLLED VOLUME PUMP. Lapp Insulator Co., Bulletin 440, 24 pp. Information on manual and automatically-controlled diaphragm-type controlled volume pumps. Covers specifications of these units and their application to automatic volume adjustment from commercial pneumatic instruments.

(58) INDUSTRIAL ELECTRONIC COUNTER. Post Machinery Co., Bulletin, 4 pp. Contains information on a line of general purpose electronic instruments used for counting all industrial products that can interrupt a beam of light. Single, double and triple decade counters are discussed.

(59) CHART DRIVES. Seth Thomas Clocks, Catalog C. D. 5-54-3M, 8 pp. Has complete application data on three series of pneumatic chart drives. Discusses use of units where explosion danger or high cost of wiring makes use of electric chart drives impractical.

(60) PNEUMATIC FLOW TRANSMITTER. Brooks Rotameter Co., Bulletin 170, 4 pp. Completely illustrated. Gives operating details and specifications of force-balance float position transmitter for use with all types of pneumatic receivers and/or control instruments.

(61) GERMANIUM PHOTOTRANSISTOR. Texas Instrument Inc. Bulletin 800 describes a new n-p-n grown junction phototransistor with glass-to-metal hermetic sets. Detailed electrical-mechanical data are given plus application information.

(62) STATISTICAL QUALITY CONTROL. Marchant Calculators, Inc., Booklet, 52 pp. Tells how statistical quality control using computing and calculating equipment has been applied to an extensive manufacturing operation. Liberal illustrations and formulas indicate how to use this technique.

(63) LINEAR ACCELEROMETERS. Statham Laboratories, Inc., Bulletin AL-1, 4 pp. Information on a family of linear accelerometers for static and dynamic measurements. Units use unbonded strain gage in balanced four arm bridge and can be used in either dc or ac circuits.

(64) CONTROL VALVES. George W. Dahl Co., Inc., Catalog, 36 pp. Includes specification sheets covering technical details of control valves for process, aircraft

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4	11	18	25	32	39	46	53	60	67	74	81	88	95
5	12	19	26	33	40	47	54	61	68	75	82	89	96
6	13	20	27	34	41	48	55	62	69	76	83	90	97
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and marine service. Types of valves include two- and three-way for high pressure or vacuum service, and pneumatically-operated for continuous control.

(65) **PHOTOELECTRIC CONTROLS,** Photoswitch, Inc., Bulletin PG 5360, 74 pp. Completely illustrated with detailed illustrations, this bulletin covers 46 case histories in which the proper application of electronic and photoelectric controls have helped to reduce production. costs. Many tips are given for anyone who applies these devices.

(66) **SCALE CONTROLS.** Richardson Scale Co., Technical reference 53H. Discusses indicating and recording systems for use with hopper scales. A complete weighing, indicating and recording cycle is described.

(67) **MECHANICAL PUSH-PULL DEVICES.** Arens Controls, Inc., Bulletin 32. Application information on miniature rigid push-pull controls. Uses described include manual reset operation of inaccessible controls, direct transmission of motion, power transmission and remote indications.

(68) **MICROWAVE PRODUCTS.** Bomac Laboratories, Inc. Catalog, 4 pp. Lists detailed specifications for line of microwave products. Devices described include gas switching tubes, shutter tubes, hydrogen thyratrons, magnetrons, duplexers and diodes.

(69) **METERING GAS FLOW.** Builders-Providence, Inc., Bulletin 100-L5, 8 pp. Describes the application of venturi tubes to measuring the flow of gas at large volumes or at low pressures and compares operation with comparable orifice plate installation.

(70) **DECADE COUNTER TUBE.** Sylvania Electric Products, Inc., Data sheet 6476, 4 pp. Principles of operation, specifications and application data on a multiple output cold cathode, bi-directional decade counter. Tube is for use in medium-speed decimal counting apparatus such as computers, scalers and dividers.

(71) **ELECTRONIC PROCESS CONTROL.** Manning, Maxwell & Moore, Inc., Catalog 164, 28 pp. Information on a system of electronic control devices for use in process control applications. Includes description of a miniature recorder, indicating control station, controller, manual positioner and electro-pneumatic valve positioner.

(72) **PAPER MILL DRIVE CONTROL.** Westinghouse Electric Corp., Catalog B-6073, 15 pp. Practical engineering data on a magnetic amplifier regulating system for paper mill drives. Outlines principles of magnetic amplifier control and shows schematic diagrams and circuits applying this type of control to typical drives.

(73) **HYDRAULIC AND PNEUMATIC CONTROLS.** Barksdale Valves, Catalog 4G, 33 pp. Contains specifications and cutaway illustrations of a diversified line of manual and solenoid operated 2-, 3-, and 4-way pneumatic and hydraulic valves. Also includes data on a variety of pressure switches with table to assist in switch selection.

(74) **INSTRUMENT GENERATOR.** Dalmotor Co., Data Sheet GPM-44A. Describes a permanent-magnet, continuous duty generator recommended as a precision voltage source. Outline dimensions, physical and electrical characteristics, and operating parameters are given.

(75) **NEOPRENE RUBBER.** E. I. du Pont de Nemours & Co., Neoprene Notebook 59, 8 pp. Part of a regular series. This issue covers engineering data important in the selection of rubber for applications involving vibration or continuous flexing, plus several case histories of Neoprene applications.

(76) **TEMPERATURE CONTROL.** Burling Instrument Co., Inc., Bulletin 103. Describes series of temperature sensitive devices using difference in coefficient of expansion of two solid tubes to actuate a switch. Can be used for on-off control of temperature or for high or low safety alarms up to 1,000 F.

(77) **MICROWAVE GAS TUBES.** Roger White Electronic Devices, Inc., Bulletin A-20, 6 pp. Information on operating principles and uses of microwave gas control tubes, including applications as absorption attenuators, reactance modulators and switches, and phase shifters.

(78) **TUBE FITTINGS.** Special Screw Products Co., Bulletin K-151, 8 pp. Construction, application and installation data on a line of stainless steel fittings featuring metal-to-metal seals reinforced with Teflon gaskets.

(79) **POWER SUPPLIES.** Dressen-Barnes Corp., Catalog, 4 pp. Describes a variety of closely regulated dc power supplies for research and development applications. Performance data, curves and physical characteristics are given for ten models.

(80) **TEMPERATURE INDICATOR.** Beckman & Whitley, Inc., Data Sheet 196. Information on several types of thermistor temperature indicating instruments. Details on mounting thermistor sensing element in an aspirated shield, Thornthwaite shield, probe and aircraft wing-mounted shield are given.

(81) **SOLENOID VALVES.** Eclipse Fuel Enginering Co., Bulletin M-500, 4 pp. Includes details on the design and performance characteristics of a line of diaphragm operated solenoid valves. Specifications cover valve use in control and cycling operations on equipment using a variety of liquids and gases.

(82) **RESISTANCE ELEMENTS.** International Resistance Co., Bulletin T-1, 4 pp. Comprehensive data on tolerances, resistance values, power and voltage ratings, machining techniques, and temperature and voltage coefficients for resistance strips and concentric disc resistors.

What's New

BOOKS

Universal Math Wrench

RELAXATION METHODS. *D. N. de G. Allen, Reader in Applied Mathematics, Imperial College of Science and Technology, University of London, 6 by 9 in., 257 pp. Published by McGraw-Hill Book Company, Inc., 330 W. 42nd St., N. Y. 36, N. Y. $7.50*

Describing a versatile method of problem solution not well known in this country, this book is written by an expert on the subject. The first application of this powerful computational procedure was made by Sir Richard Southwell of the University of Oxford in 1935. Its fundamentals extend into the theory of finite differences and overlap other mathematical methods. This is the first book which shows the reader how to use the techniques of relaxation, instead of merely describing what relaxation can achieve.

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Engineering Economics

BUSINESS, LEGAL, AND ETHICAL PHASES OF ENGINEERING. *D. T. Canfield, Professor of Electrical Engineering, Purdue University and J. H. Bowman, Professor of Electrical Engineering, Purdue University, 6 by 9 in., 365 pp. Published by McGraw-Hill Book Company, Inc., 330 W. 42nd St., N. Y. 36, N. Y. $6.00*

This is a second edition of a successful text which teaches engineering economics to the engineer. The new edition has been generalized, and is applicable to all fields of engineering. The chapters on Accounting and Patents have been almost entirely rewritten. Two have been added: "Business Organizations" and "Stocks, Bonds, and Notes." Proprietorships, Partnerships, Corporations are discussed.

The book has four parts: 1) Business Economy, 2) Cost Determination, 3) Business Law, and 4) Engineering Procedures. Typical chapter heads are: Money, Interest and Discount; Annuities and Sinking Funds; Insurance, Bond Interest and Amortization; under "Business Economy." "Cost Determination" chapters include: Distribution Factors; Financial Reports and Records; Allocation of Burden, or Overhead; and Public Utility Rates. Law and The Courts; Contracts of Commerce; Lawful Subject Matter; and other chapters are under "Business Law." Part four chapters are: Engineering Bids and Specifications; Patents, Copyrights, and Trade-Marks; Insurance, Industrial Hazards, and Employment Compensation; The Practice of Engineering; and Engineering as a Profession.

All About Pots

TIC POTENTIOMETER HANDBOOK. *6 by 9 in., 207 pp., Published by Technology Instrument Corporation, 531 Main Street, Acton, Mass. $2.00*

This loose-leaf handbook gives a detailed treatment of nearly all phases of potentiometer theory, design, performance, and application. The book is well illustrated, and includes within the same binder a catalog of Technology Instrument Corporation's potentiometers.

The first three sections describe precision potentiometer terms and illustrate potentiometer component parts. Cutaway drawings clearly show structural details.

Potentiometer performance characteristics, such as linearity, conformity, resolution, noise, power rating, frequency response, corrosive effects, mechanical acceleration, and operating life are treated in Sections 4 through 7.

The design, construction, and performance of both linear and nonlinear potentiometers are presented in detail in Sections 8, 9 and 10. Particular emphasis is given to the different methods for generating precise nonlinear functions with potentiometers.

Section 11 deals with the methods for mounting and ganging potentiometers, and Section 12 describes such special potentiometer designs as multiturn, slide wire, translatory, and differential potentiometers. The principle of operation of each of these types is clearly illustrated. Section 13 is a bibliography of the books, periodicals, papers, and specifications that comprise the principle literature in the field of precision potentiometers.

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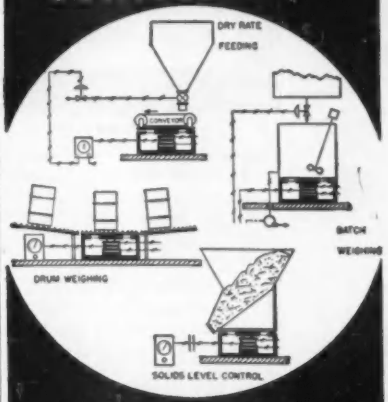

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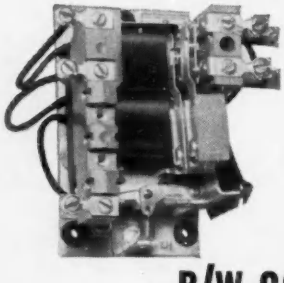

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Magnetic Controllers

MAGNETIC-AMPLIFIER CIRCUITS. *William A. Geyger, Magnetics Division, U. S. Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland, 6 by 9 in., 277 pp. Published by McGraw-Hill Book Co., 330 W. 42nd St., N. Y., 36 N. Y. $6.00*

The fundamental principles, characteristics, and applications of magnetic-amplifier circuits are expounded in this book. It develops basic and more complex circuit arrangements, emphasizing experimentally observed phenomena and avoiding extended mathematical considerations and cumbersome proofs. It uses descriptive and graphical methods to give a qualitative and quantitative interpretation of the essential facts.

Chapter 1 gives a classification of saturable-core devices and reviews the history of magnetic amplifiers. Chapter 2 describes magnetic core materials, different kinds of core construction, winding arrangements, and various types of rectifier devices, as used in magnetic-amplifier circuits. In Chapters 3 to 16, the book presents a systematic description of the numerous types of magnetic-amplifier circuits: non-feedback circuits, single-stage and multistage circuitry utilizing external or internal feedback, and special circuits using critical regeneration or derivative feedback, etc.

Chapters 17 and 18 discuss the technical properties, transient response, and typical applications of magnetic amplifiers, particularly those in instrumentation, in servomechanisms, in regulators and automatic control devices, and in electronic arrangements.

Differential Equations

ELEMENTARY DIFFERENTIAL EQUATIONS. *Lyman M. Kells, Professor of Mathematics, U. S. Naval Academy, 6 x 9 in., 266 pp., Fourth Edition. Published by McGraw-Hill Book Co., 330 W. 42nd St., N. Y. 36, N. Y. $4.00*

This is a new edition of the famous text dealing with the solution of the types of differential equations most important to the engineer. It has been thoroughly revised to emphasize theory with increased simplicity. Most of the discussions have been rewritten and expanded. Nearly all the lists of problems have been revised for quicker

comprehension and increased value.

This book is noted for its discussions of practical applications of differential equations. Chapters describing a particular kind of equation, its mathematical properties, and methods of solution are followed by chapters detailing engineering application of the equation. For example; following the chapter on "Linear Differential Equations with Constant Coefficients," there is a chapter dealing in some detail with harmonic motion, damping, forces, acceleration, vibratory motion, and resonance.

Atomic Optics

OPTICAL INSTRUMENTATION. *Edited by George S. Monk, Associate Professor Emeritus of Physics, University of Chicago, and W. H. McCorkle, Director, Laboratory Research Reactor Operations Division, Argonne National Laboratory, 6 x 9 in., 262 pp. Published by McGraw-Hill Book Co., 330 W. 42nd St., N. Y. 36, N. Y. $3.75*

This volume is one of a series which has been prepared as a record of the research work done under the Manhattan Project and the Atomic Energy Commission. During the short period between the start of the Optics Section of the Metallurgical Laboratory in the fall of 1943 and its disbandment in the summer of 1945, the Section was called upon to design and build many dozens of optical instruments for remote control in irradiated areas. Practically all of these were to be used under conditions never before encountered, and materials suitable for these conditions either did not exist or were not at all plentiful.

Part I of this volume presents the fundamental requirements as they appeared at the time and the general way in which they were met. Part II is a series of condensed reports describing typical instruments which were built and certain technical processes, the study of which was essential to the work of the Section.

Part I is titled "Survey of Optical and Associated Problems." Chapters are: Optical Problems in the Metallurgical Project; Optical Instruments for Viewing in Irradiated Areas; and Miscellaneous Instruments and Services of the Project Optical Section. Collected papers in Part II include: Design of a Kellner-type Plastic Objective; Achromat with Positive Element of Two Plastic Field Lenses; and Miscellaneous Notes on Coloration of Optical Materials; Waterproof Cements and Their Suitability in Optical Construction.

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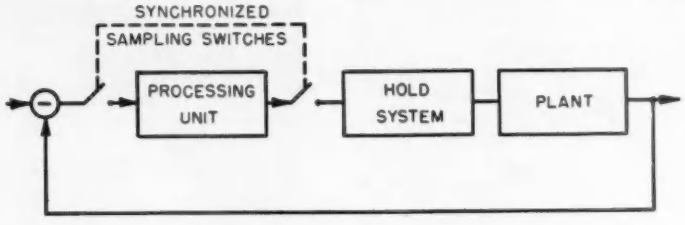

Sampled-data Techniques

From "Sampled-Date Processing Techniques for Feedback Control Systems" by A. R. Bergen and J. R. Ragazzini, Electronics Research Labs., Columbia University. Paper presented at the AIEE Pacific General Meeting, Los Angeles, California, June 1954.

Sampled-data feedback control systems are being used more often. Digital computers, time-shared data-transmission links, and radar data-gathering devices used as control elements catalyze this growth.

The controlled plant is generally represented as a continuous linear device, often having transfer lags. Stabilization and shaping of a feedback control system for such a plant, where data are sampled at one or more points in the system, is a central problem. Prior methods have utilized linear networks in cascade with the plant which shaped the plant transfer function to give acceptable performance. An alternate method is to process the data samples themselves, in a computer or processing unit, to produce an output pulse sequence which stabilizes and shapes the over-all system response.

The sampled-data processing unit is a device interposed between the summing point and the actuating signal to the controller, which operates by storing a number of error samples received from the summing point, does the same with past samples of its own output, weights them in a specified way, and delivers the modified output as an actuating signal to the system controller. Such a processing unit operates only during the sampling interval. The processing unit, then, compares the result of a past output with that output and the desired result, and modifies the new output accordingly. Such a device can make the response of a system conform with desired specifications.

In theory, it is always possible to design a sampled-data processing unit to synthesize an internal transfer function which results in an overall transmission by the prototype functions with a finite settling time. A number of practical considerations, however, may make the realization of such functions impossible or impractical. The paper describes two major limitations mathematically, and gives an illustrative example. The first restriction is the physical one represented by saturation in the plant. It may be restated: the input error sequence applied to the plant cannot be allowed to exceed a certain maximum value. If it does, the plant will not respond linearly, and will, in effect, limit the output. The second limitation is the mathematical one brought about because the processing unit cancels undesired poles or zeros in the pulsed plant transfer function and replaces them with desired poles and zeros. Since it is not always possible to obtain perfect cancellation of the unwanted poles and zeros, and since imperfect cancellation might result in system instability, certain limitations in design are evolved.

The paper concludes with considerations of implementation of these processing units.

Measure Transfer Functions

From "Self Oscillation Method for Measuring Transfer Functions" by J. C. Clegg and L. C. Harris, Dept. of Electrical Engineering, University of Utah. AIEE "Transactions" Paper No. 54-284.

Transfer function data are obtainable without the use of a separate sinusoidal generator or driver if the system is allowed to oscillate and thus supply its own driving force. Furthermore, measurement of magnitude and phase is unnecessary. The frequency of oscillation must be measured, but this quantity is easily and accurately observed.

Cascading the unknown system with

an auxiliary, calibrated system, and including both within a feedback loop, produces the overall response:

$$\frac{\theta_o}{\theta_i} = \frac{G_T}{1 + G_T}, \qquad (1)$$

where G_T is the transfer function of the composite system. When the system is in steady-state oscillation, θ_o is finite and θ_i is equal to zero; the denominator of equation (1) must be equal to zero, i.e.,

$$1 + G_T = 0, \qquad (2)$$

but

$$G_T = GG_e \qquad (3)$$

therefore

$$G = -\frac{1}{G_e}. \qquad (4)$$

If the composite system is allowed to oscillate, the unknown transfer function G is related to the known or calibrated transfer function G_e as shown by equation (4). The calibrated system has phase shift and attenuation characteristics which are adjustable, and which are known for every frequency of oscillation. The calibrated system also contains a saturating element to control the amplitude of oscillation. The transfer function of the non-linear element is readily found by describing function concepts.

Changing the phase shift characteristics of G_e controls the frequency of oscillation. The level of saturation in the saturating element controls the amplitude of oscillation. But, if the system under test contains significant non-linearities, then the level of saturation will affect the frequency of oscillation and the phase control will alter the amplitude of oscillation.

The adjustable attenuation characteristics of the calibrated system must in general, include an amplifier to get both positive and negative attenuations. In use, the attenuation level is set for a stable oscillation in which the signal does not swing excessively into the saturation region of the saturating element.

Regulating Power Frequency

From "Performance of a Constant Speed Drive" by E. W. Gilroy, The Glenn L. Martin Company. Paper presented at the AIEE Pacific General Meeting, Los Angeles, California.

The main propulsion engines are the obvious source of all power (excepting batteries) aboard an airplane in flight. They are also naturally poor

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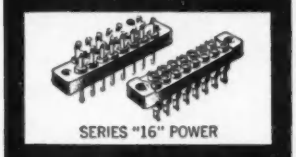
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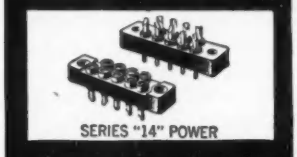
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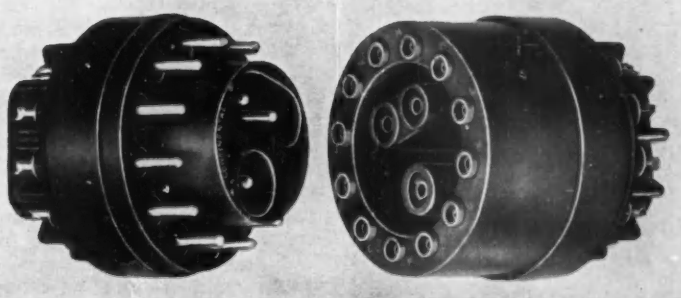

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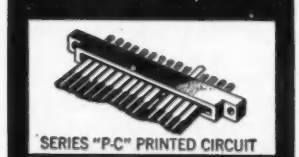
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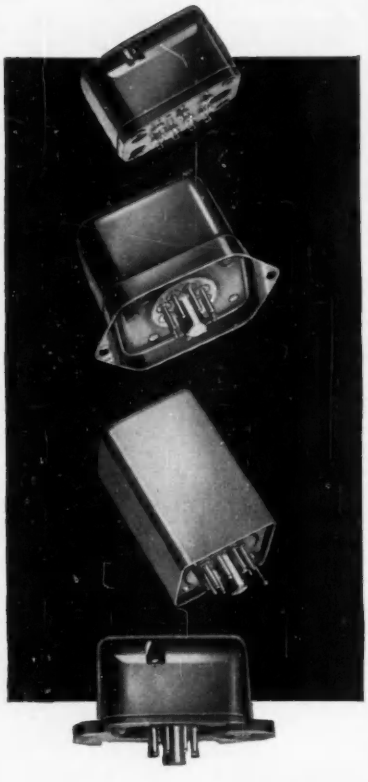

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ABSTRACTS

a four-cycle droop under full load conditions.

The paper includes detailed and frank discussion of laboratory and service experience, and concludes by suggesting the areas where further effort should be extended to improve reliability and performance standards.

Impulse-Response Design

From "The Design of Sampled-data Feedback Systems" by G. V. Lago, Dept. of Electrical Engineering, University of Missouri, and J. G. Truxal, School of Electrical Engineering, Purdue University. AIEE "Transactions," Paper No. 54-283.

The sampling process both simplifies and complicates the design of the control system. Because the loop is closed only during the sampling times, the system operates most of the time open-loop, and evaluation of the response is a simple open-loop analysis problem. The intermittency of the closing of the loop, however, introduces stability problems nonexistent in the continuous system.

By its very nature, a sampled-data system should be more easily analyzed than the corresponding continuous system. Indeed, some of the most powerful methods for the analysis of continuous systems are based on sampled approximations of the continuous functions. The most promising appears to be the z-transformation. The main limitation of the z-transform is that it describes the response only at the sampling instants. Since an infinite number of sampled-data systems have the same response values at the sampling instants, other techniques must be made to determine the complete response. The uncertainty of the z-transform method between sampling instants is partially removed by finding the output at submultiples of the sampling period, and is entirely removed by the impulse response approach.

The z-transformation method gives a comprehensive picture of absolute stability, but this is not the problem the engineer faces when he tries to meet such specifications as maximum overshoot. The impulse response approach can be used to set the gain to meet overshoot specification, and the controlled element transfer function in most cases indicates the nature of the compensation network needed to meet the specifications. Thus, shaping the impulse response of the open-loop system provides the optimum method for design of sampled-data sys-

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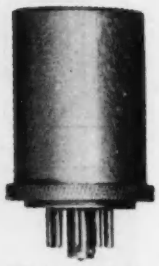

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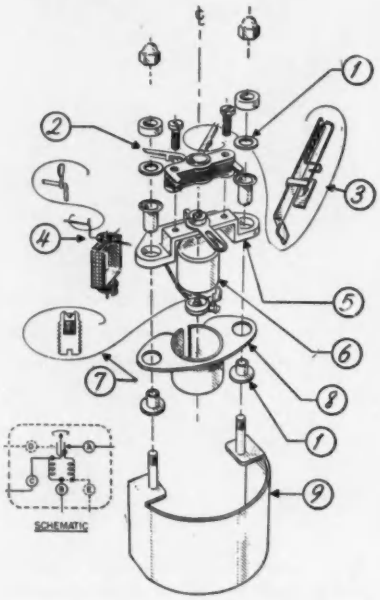

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ABSTRACTS

tems. The z-transformation and Nyquist diagram increase the designer's circumspection.

Induction Pots

"Induction Potentiometer as an Analog Position Indicator" describes the physical and performance characteristics of this useful component. Points covered include: standardization and compensation, core effects, residual voltages, design, and application. "Product Engineering," August 1954, pages 138 to 143.

Servos

"Six Basic Control Systems" gives brief, illustrated descriptions of 1) basic electromechanical servo loop; 2) on-off servo with mechanical feedback; 3) inductive servo system; 4) inductive system with indirect feedback; 5) remote servo using bridge-balancing network; 6) remote servo using synchro transmission. This article also describes the effect on system response produced by using rate control, mechanical damping, and integral control. "Product Engineering," July 1954, pages 179 to 183.

Computers

"Tape Recorder Stores Computer Output" describes the use of a tape recorder as a buffer between high-speed computers and slow-speed printers. If further processing is required, the stored data may be read back into the computer. "Electronics," July 1954, pages 166 to 169.

Analog Analysis

"Test Models" discusses the use of models and analogs to predict the static and dynamic behavior of physical systems. The article relates the differences between conventional models and analogs, and describes the use of an electrical analog to predict the performance of a fluid flow system. "Chemical Engineering," July 1954, pages 183 to 189.

Automatic Processing

"Why Automation Is for You" is a question-and-answer session with an expert in applying automatic controls to production machines. The use of automatic machinery in assembly, inspection, and packaging is discussed, as well as the initial cost and the savings which may be expected therefrom. "Factory Management and Maintenance," July 1954, pages 80 to 89.

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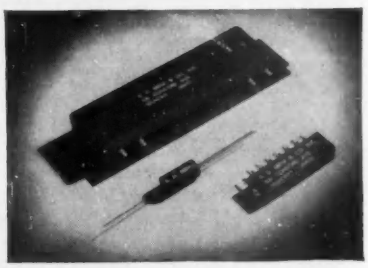

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What's Ahead

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American Society of Mechanical Engineers, Fall General Meeting, Schroeder Hotel, Milwaukee, Wisc. Sept. 8-10

Instrument Society of America First International Instrument Congress & Exposition, Convention Hall, Philadelphia. Sept. 13-24.

Symposium on Information Theory, Massachusetts Institute of Technology, Cambridge, Massachusetts. Sept. 15-17

October

National Electronics Conference, Inc., Hotel Sherman, Chicago, Ill. Oct. 4-6

Society of Automotive Engineers (National Aeronautic Meeting) Statler Hotel. Oct. 4-9

American Institute of Electrical Engineers (fall general meeting) Morrison Hotel, Chicago, Ill. Oct. 11-15

National Conference on Industrial Hydraulics, 10th annual meeting, (devoted to hydraulic control), Sheraton Hotel, Chicago, Ill. Oct. 14-15

November

National Electrical Manufacturers Association, Annual Meeting, Haddon Hall Hotel, Atlantic City, New Jersey. Nov. 8-11

American Petroleum Institute, 34th Annual Meeting, Conrad Hilton Hotel and Palmer House, Chicago, Ill. Nov. 8-11

American Standards Association, (Fifth National Conference on Standards and Thirty-sixth Annual Meeting), Hotel Roosevelt, New York, N. Y. Nov. 15-17

The American Society of Mechanical Engineers, Annual Meeting, Statler Hotel, New York, N. Y. Nov. 28-3

December

National Exposition of Power and Mechanical Engineering, Commercial Museum, Philadelphia, Pennsylvania. Dec. 2-7

Eastern Computer Conference, Bellevue-Stratford Hotel, Philadelphia, Pa. Dec. 8-10

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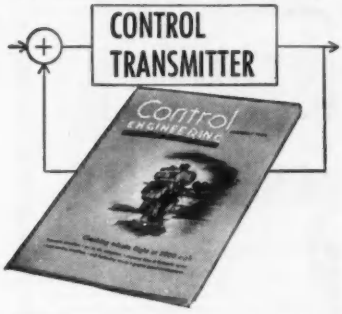

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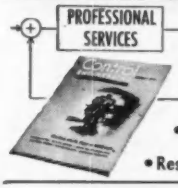

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Listed below are frames and coils from our stock. They may be purchased separately. However, a complete relay consists of coil and frame. In ordering complete relays specify which coil with which frame, i.e.: F101 with K117.

Representative completed relays are also listed with voltage and current ratings. Values are indicative of sensitivity that may be expected from similar combinations.

CLARE, 6500 ohm, 8 ma DC, 3 makes (3As) #R276 **$4.25**

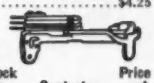
CLARE K101, 6500 ohm, SPDT, 2 ma DC. Fast Action R588 ..... **$4.25**

AI8258 BENDIX (Cook 102) 8-12 VDC, Copper Slug. Slow Release. SPDT, 200 ohm. Part of SCR 522. #365 ..... **$2.49**

R5229A1 AUTOMATIC 6VDC, 3PST n.o. (3As), 75 ohms. Slow Release, #412..... **$2.50**

R5021A1 AUTOMATIC 1300 ohm, 12 ma DC, SPST n.c. (1B). #413..... **$2.95**

FRAMES



(For Cost of Relay Add Price of Frame to Price of Coil)

Stock No.	Contacts	Price each	Stock No.	Contacts	Price each
F101	1A	$1.25	F108	1B, 1A, 1C	2.00
F102	2A	1.50	F131	1B, 9A, 1C	4.00
F103	3A	1.75	F107	2B, 1A	1.75
F104	4A	2.00	F142	2V, 2A	2.00
F138	5A	2.25	F112	2B, 2A, 2C	3.00
F139	10A	3.50	F129	2B, 2A, 6C	5.00
F128	12A	4.00	F140	3B, 1A	2.00
F106	1A, 1B	1.50	F121	5B, 1C	2.75
F107	1A, 2B	1.75	F122	1C	1.50
F140	1A, 3B	2.00	F123	2C	2.00
F108	1A, 1B, 1C	2.00	F145	3C	2.50
F109	1A, 1C	1.75	F124	4C	3.00
F141	1A, 3C	2.75			
F111	2A, 1B	1.75	F109	1C, 1A	1.75
F142	2A, 2B	2.00	F137	1C, 2A	2.00
F137	2A, 1C	2.00	F117	1C, 5A	2.75
F142	2A, 2C	2.50	F133	1C, 1B	1.75
F112	2A, 2B, 2C	3.00	F108	1C, 1A, 1B	2.00
F129	2A, 2B, 6C	5.00	F121	1C, 5B	2.75
F114	3A, 1B	2.00	F131	1C, 9A, 1B	4.00
F115	3A, 2C	2.75	F142	2C, 2A	2.50
F117	5A, 1C	2.75	F112	2C, 2A, 2B	3.00
F143	6A, 4C	4.50	F115	2C, 3A	2.75
F131	9A, 1B, 1C	4.00	F141	3C, 1A	2.75
F147	1A, 2D	2.75	F144	4C, 1B	3.24
F148	2A, 1D	2.25	F143	4C, 6A	4.50
F120	1B	1.25	F129	6C, 2A, 2B	5.00
F132	2B	1.50	F149	1C, 1D	2.25
F134	3B	1.75	F150	3C, 1D	3.25
F106	1B, 1A	1.50	F151	1D	1.75
F111	1B, 2A	1.75	F148	1D, 2A	2.25
F114	1B, 3A	2.00	F149	1D, 1C	2.25
F133	1B, 1C	1.75	F150	1D, 3C	3.25
F144	1B, 4C	3.24	F147	2D, 1A	2.75

Additional pileups also available

A = Normally open; B = Normally closed;
C = Double throw; D = Make before break

COILS

(For Cost of Relay Add Price of Coil to Price of Frame)

Stock No.	Ohms	Price each	Stock No.	Ohms	Price each
K101	0.75	$1.25	K107	750	$1.50
K131	5.0	1.25	K135	800	1.75
K102	12	1.25	K109	1000	1.75
K156	50	1.25	K111	1300	1.75
K157	70	1.25	K158	1400	2.00
K132	175	1.25	K112	2000	2.25
K153	300	1.50	K159	2250	2.50
K154	400	1.50	K155	2500	2.50
K104	450	1.50	K113	3000	2.50
K105	500	1.50	K116	6500	2.75
K133	600	1.50	K167	12,000	3.00
K134	700	1.50	K118	40,000	3.25

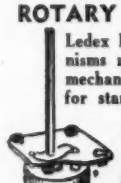
SLOW-ACTION COILS

SLOW-MAKE Stock No.	Ohms	Price each	SLOW-RELEASE Stock No.	Ohms	Price each
K160	20	$1.50	K161	30	1.50
K122	33	1.50	K149	3.9	1.50
K146	125/1300	2.50	K123	75	1.50
K147	500/1500	2.50	K124	200	1.50
K148	1300	2.00	K150	800	2.00
K146	1300/125	2.50	K151	1000	2.00
K147	1500/50	2.50	K152	1300	2.25

DUAL COILS

Stock No.	Ohms	Price Each	Stock No.	Ohms	Price each
K162	20/400	2.25	K106	500/1100	2.00
K163	25/200	2.25	K144	500/1800	2.50
K141	50/2000	2.25	K165	550/550	2.25
K166	125/125	2.25	K143	1000/200	2.00
K142	125/1300	2.25	K109	1100/500	2.00
K164	200/200	2.25	K142	1300/125	2.25
K163	200/25	2.25	K144	1800/500	2.50
K143	200/1000	2.00	K141	2000/50	2.25
K162	400/20	2.25			

ROTARY RATCHET RELAYS



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#25 Mechanism Only, 12-18V, 4.5 ohm, #R824 ..... **1.50**

#26 Mechanism Only, 6-8V, 2 ohm, #R825 ..... **1.50**

Miniature Mechanism Only, 12-24V, 35 ohm, #R826 ..... **1.50**

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Clare	BR2	Long Relay Bracket	#BR2.. .20
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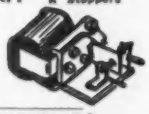

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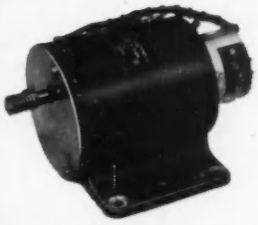

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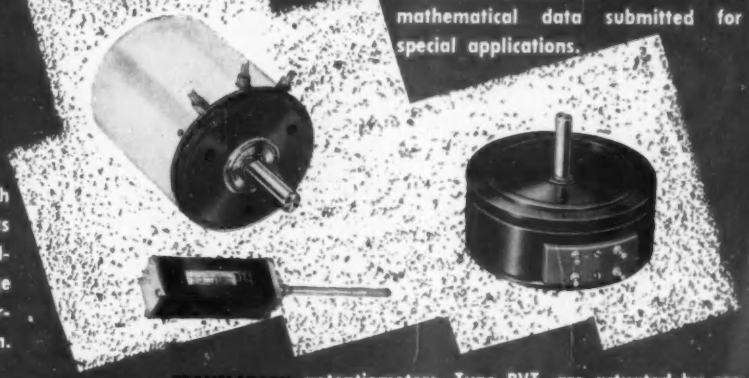

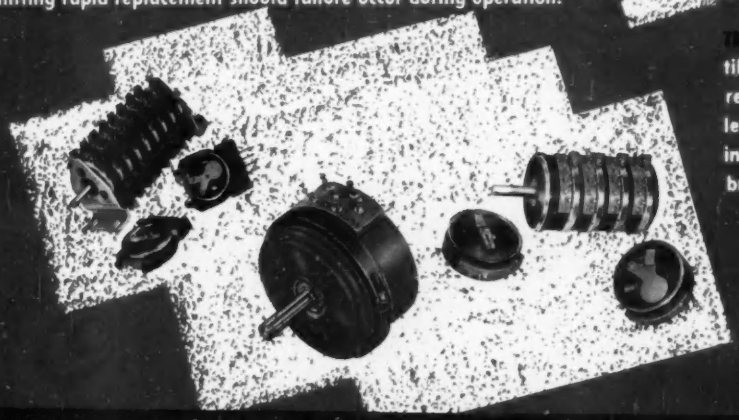

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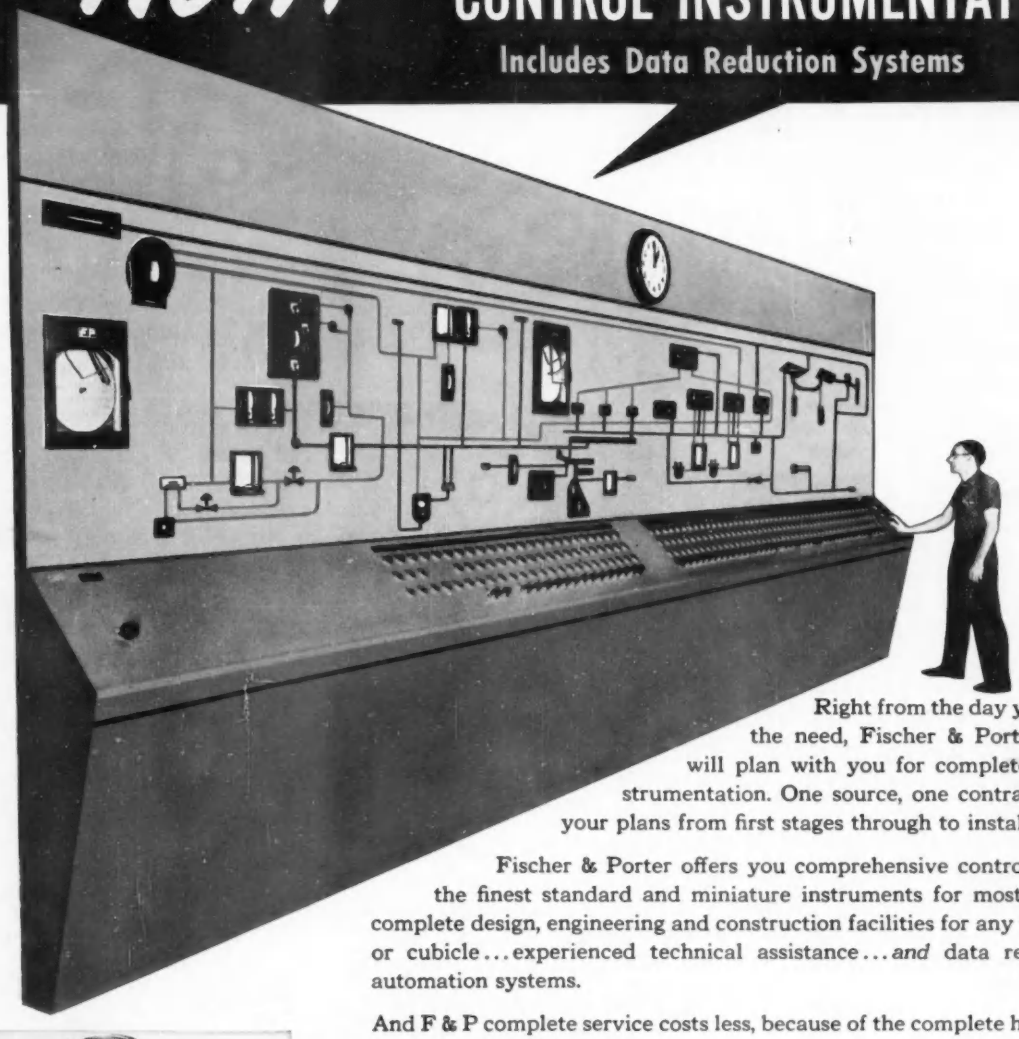

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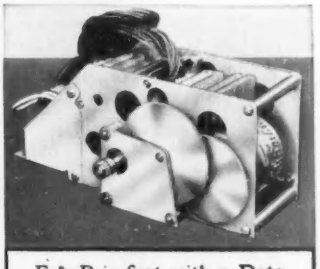

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